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AAFCS M33 TECHNICIAN TRAINING PROGRAM. VOLUME II. ELECTRONIC FU--ETC(U)

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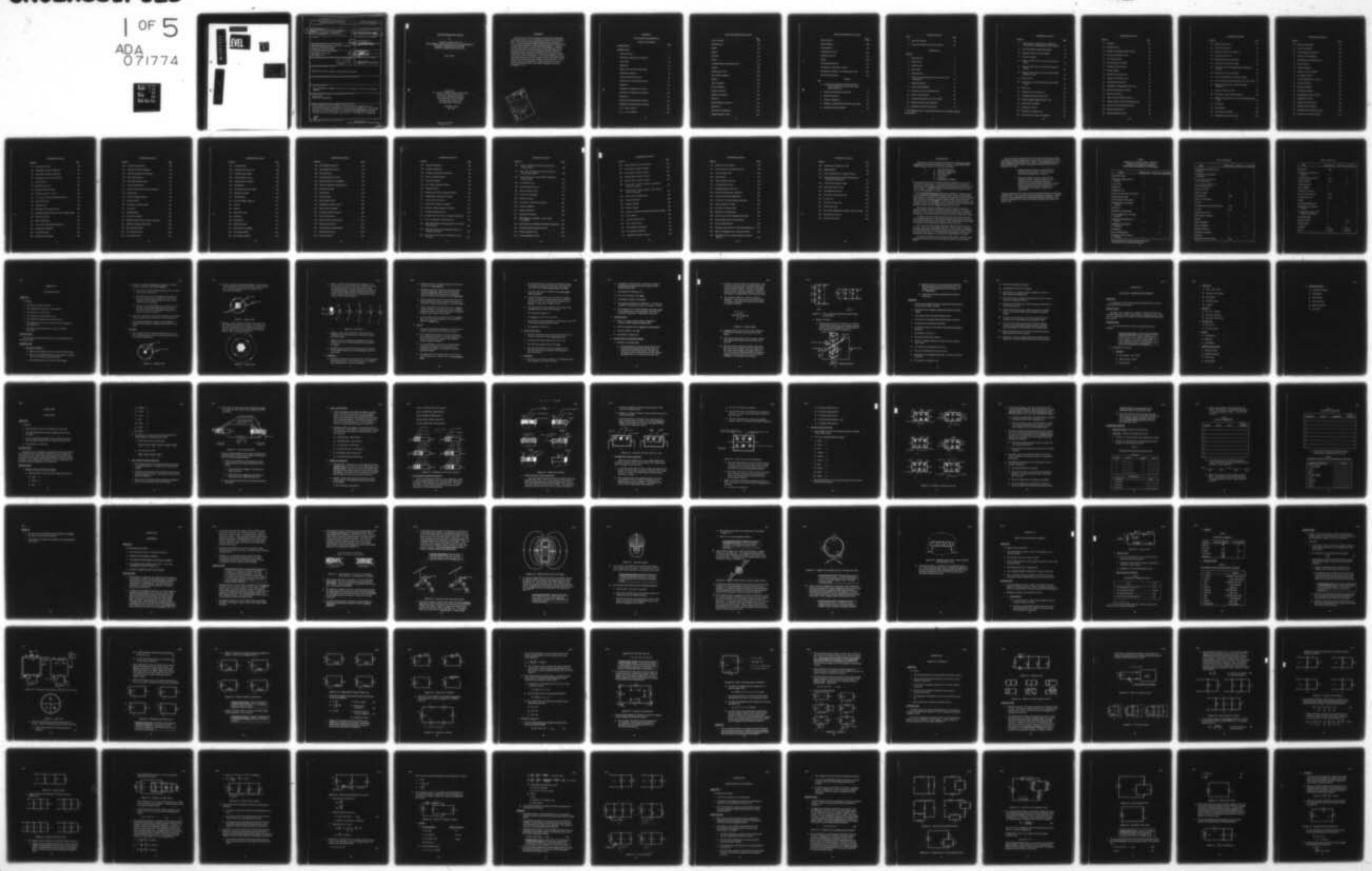

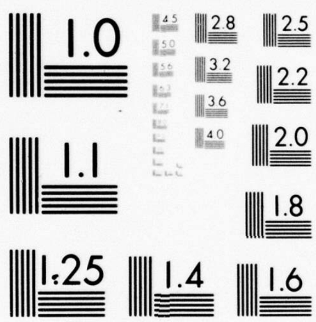

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This is Volume II of six volumes of training material prepared for an experimental course of maintenance instruction on the AAFCS M33. This volume contains instructional material for the Electronic Fundamentals subcourse of a program of fire control radar instruction. It includes lesson plans and practical exercises, designed to be covered in 195 periods of instruction.

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Technical Supplementary Material

for

HumRRO Technical Report 46:
DEVELOPMENT AND EVALUATION OF AN EXPERIMENTAL PROGRAM OF INSTRUCTION FOR FIRE CONTROL TECHNICIANS (RADAR VI)

Lesson Plans

Prepared By
U.S. Army Air Defense Human Research Unit
Under the Technical Supervision of
The George Washington University
Human Resources Research Office
operating under contract with
The Department of the Army

Fort Bliss, Texas
June 1958

FOREWORD

This is volume II of six volumes of training material prepared for an experimental course of maintenance instruction on the AAFCS M33. This material was developed during research conducted by the U.S. Army Air Defense Human Research Unit at Fort Bliss, Texas, in cooperation with the U.S. Army Air Defense School. A detailed account of the research, results, and recommendations emerging from the experiment, and the rationale by which this material was prepared and used, is included in HumRRO Technical Report 46, "Development and Evaluation of an Experimental Program of Instruction for Fire Control Technicians." It is recommended that readers familiarize themselves with the contents of this report before attempting to use the training material contained in these volumes. A copy of this report may be obtained by writing to the Director, Human Resources Research Office, The George Washington University, Washington 7, D. C.

VOLUME II

ELECTRONIC FUNDAMENTALS

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TABLES (continued)

DIAGRAMS 1/

1/ Diagrams refer to drawings which have been specially prepared by the authors.

DIAGRAMS (continued)

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INTRODUCTION

This volume contains instructional material for the Electronic Fundamentals (basic electronics) subcourse of a program of fire control radar instruction that consists of the following subcourses:

I	Operation Orientation
II	Electronic Fundamentals
III	Acquisition Radar
IV	Track Radar
V	Computer
VI	Maintenance and Supply

It includes lesson plans and practical exercises, designed to be covered in 195 periods of instruction: 111 periods of conference and 84 periods of practical exercises. 2/ Each instructional period was approximately 50 minutes in length. A detailed breakdown of instructional topics and time allotment is presented in table 1, page 3.

The Electronic Fundamentals subcourse is designed to acquaint the student with selected basic physical principles which underlie the functioning of all electronic circuits and the operation of several basic circuits commonly found in electronic systems. Several additional basic circuits, including those found only in the AAFCS M33, were not covered in this subcourse. The operation of these circuits is discussed in conjunction with the coverage of the specific portions of the M33 system of which they are a part.

Instructional material contained herein is that issued to instructors. Material issued to students was identical with two exceptions: (1) copies of practical exercises were not issued, and (2) instructor's notes, suggested explanations, and problems (shown in boxes in the lesson plans) were deleted.

A difference in format exists between material in this volume and that used during the research, in that the experimental lesson plans were printed only on the left-hand pages of the volumes. This arrangement provided student and instructor with convenient and appropriate space for notes.

It will be noted that each page of the lesson plans is coded at the top of the page. This code is interpreted as follows: the first letter "I" indicates that these publications were issued to instructors, the second letter indicates the volume (in this case, "F" for Electronic Fundamentals), and the number following the dash indicates the number of the lesson plan in the volume.

2/ Practical exercises are not included in this volume. Standard, modified practical exercises were used in conjunction with the attached lesson plans.

Experience gained during the course of an experiment frequently enables researchers to suggest modifications in design and/or materials that should lead to significant improvement of the product. Such modifications have been incorporated into these volumes to the possible benefit of the user and are indicated in two ways:

1. Changes relating to content are described in the introduction to each volume. No such changes have been recommended for volume II.

2. Changes relating to topic time allotments are indicated in table 1. Numbers indicate recommended hours of instruction for each topic: where recommended time differs from time actually alloted during the experiment, actual time consumed during the experiment is indicated in parentheses.

Although materials in this volume have been carefully prepared, imperfections may still exist. Your cooperation in eliminating them is requested. Notification of errors and suggestions for improvement should be forwarded to the Director of Research, U.S. Army Air Defense Human Research Unit, Fort Bliss, Texas.

Table 1

SUMMARY OF INSTRUCTIONAL* PERIODS ALLOTTED TO TOPICS INCLUDED IN ELECTRONIC FUNDAMENTALS SUBCOURSE

TOPIC	CONFERENCE	PRACTICAL EXERCISE
Electrical Units	1	
Electrical Components and Symbols	1	
Color Code	1	
Magnetism	2	2
Multimeter Use		2
Ohm's Law and Series DC Circuit	4	4
Parallel DC Circuits	2	2
Series-Parallel DC Circuits	2	2
Introduction to Alternating Currents	1	
Inductance	1	
Resistance and Inductance	2	
Use of Oscilloscope and Audio Oscillator		4
Resistance and Inductance in Parallel	2	
Inductance and Inductive Reactance		3
Capacitance	2	
Use of Soldering Iron		3
Resistance and Capacitance in Series	2	

*Does not include five hours of nonacademic time: commander's time, physical training, etc.

Table 1 (continued)

TOPIC	CONFERENCE	PRACTICAL EXERCISE
Capacitance and Resistance in Parallel	2	
Capacitance and Capacitive Reactance		3
R, L, and C in Series and Series Resonance	2	
R, L, and C in Parallel and Parallel Resonance	2	
Resonant Circuits		4
Time Constants	4	4
Transformers	2 (4)	4
Diodes and Rectifiers	4	4
Filters	1	1
Voltage Dividers and Potentiometers	3 (2)	3
Triodes	3 (2)	
Multielement Tubes	2	
RC-Coupled Amplifiers	3	4
Biasing	1	
Video Amplifiers	4	4
Power Amplifiers	2	2
Cathode Followers	2	2
Paraphase Amplifiers	1	
Detectors	1	2
Superheterodyne Receivers	4 (2)	

Table 1 (continued)

TOPIC	CONFERENCE	PRACTICAL EXERCISE
Oscillators	4 (2)	3
Transmitter and Receiver Systems	2	
Voltage-Regulator Tubes	4 (2)	2
Diode Limiters	4 (2)	2
Diode Clampers	2	2
DC Amplifiers	2	
Coincidence Circuits	1	
Synchro Demonstration	2 (1)	
Cathode-Ray Tubes	3 (2)	
Relays	2	2
One-Shot Multivibrator	2	2
Introduction to Principles of Radar	2	
Transmission Lines, Wave Guides, and Antennas	2	
Troubleshooting	3	
Hidden Circuits		2 (4)
Examinations	8	8
Critiques	2	2
Total	111 (101)	84 (86)

LESSON PLAN

ELECTRICAL UNITS

OBJECTIVE:

To explain:

1. The basic components of matter;
2. The comparison of conductors and insulators;
3. The meaning of "current flow";
4. The necessity for electromotive force;
5. The results of resistance in an electric circuit;
6. The definitions of current, electromotive force, resistance, and charge; and
7. The units of electromotive force, current, resistance, and charge.

INTRODUCTION:

The entire field of electronics begins with an understanding of the terms given above.

PRESENTATION:

1. The Nature of Matter.
   a. Matter is any substance that has mass and occupies space.
   b. There are 96 natural elements, and all matter is composed of one or more of these natural elements.
   c. The smallest part of an element is called an atom.

d. Atoms are composed of <u>protons</u> and <u>electrons</u>. In addition to these, many atoms also contain <u>neutrons</u>.

1) Protons have a positive electrical charge and are always in the nucleus of the atom.

2) Neutrons have no electrical charge and are always in the nucleus of the atom. Neutrons have mass and contribute to the total weight of atoms but have no effect on the electrical properties.

3) Electrons are negative charges and are always moving in orbits outside of and around the nuclei of atoms. The mass of an electron is negligible compared to the mass of a proton or a neutron.

e. Since the normal atom of any element contains equal numbers of protons and electrons, the atom is electrically neutral.

f. The fundamental difference between atoms of different elements is in the number of protons and electrons in each atom.

2. <u>Elements</u>.

a. The simplest element is hydrogen whose atom has one proton as a nucleus and one electron moving around the nucleus in a circular orbit (diag 1).

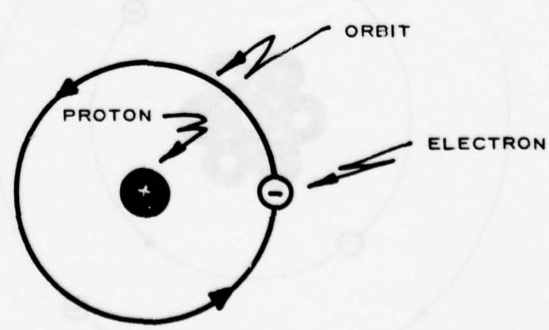


Diagram 1. Hydrogen atom.

b. Helium, a heavier element than hydrogen, has two protons and two neutrons in the nucleus of the atom. Two electrons move around the nucleus in orbits at equal distances from the nucleus (diag 2).

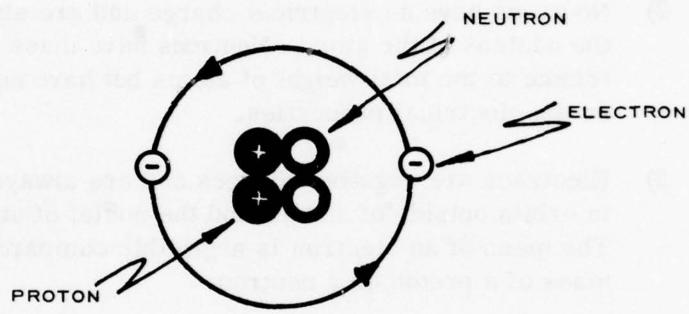


Diagram 2. Helium atom.

c. Lithium, a metal, has three protons in the nucleus of its atom and three electrons in the orbits. Two orbital electrons are in orbits near and at equal distances from the nucleus, while the third electron moves in an orbit outside the orbits of the first two (diag 3).

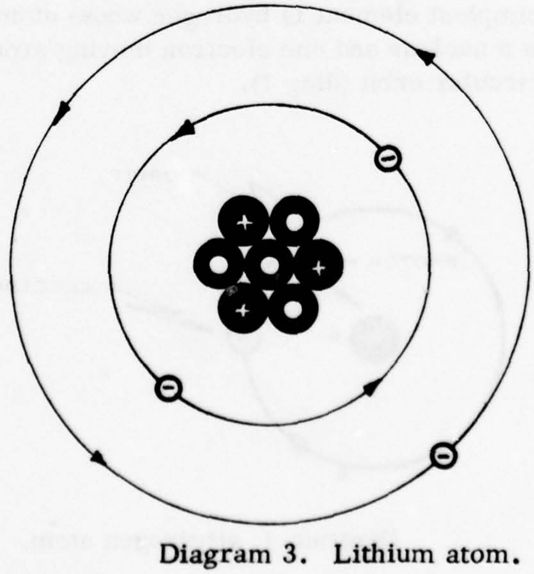


Diagram 3. Lithium atom.

d. Silver, a metal, has 47 protons and 47 electrons. The protons are in the nucleus of the atom, while the electrons are arranged in layers, or shells, around the nucleus. The first shell (layer of orbits) contains two electrons, the second shell has eight electrons, and the third and fourth shells contain 18 electrons each. The fifth shell contains only one orbital electron (diag 4).

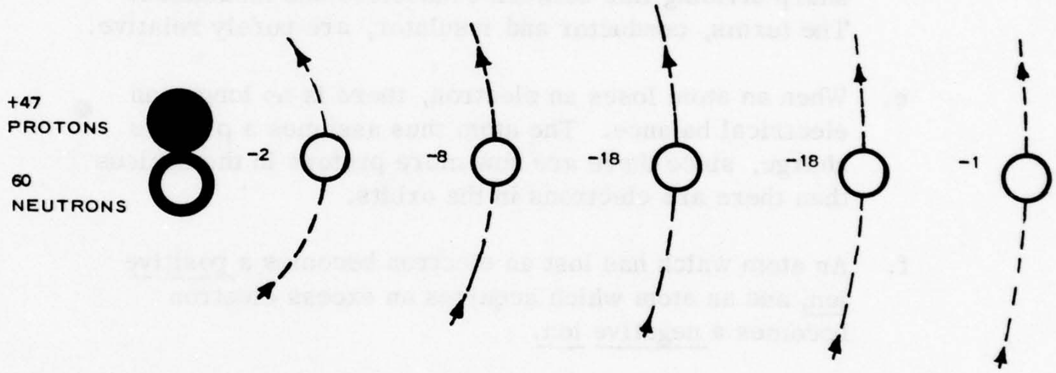


Diagram 4. Silver atom.

e. Copper, a metal, has 29 electrons. The electrons are arranged in four shells with only one electron in an orbit in the outer shell.

f. With the exception of hydrogen and helium, any element which has one, two, or three electrons in the outer shell is a <u>metal</u>.

g. Metals may lose one electron from their outer shell owing to such outside influences as thermal agitation or electrostatic fields.

3. <u>Conductors</u>.

a. The atoms of metals in the solid state have a free exchange of outer shell electrons. These electrons are in a continual state of movement from one atom to another.

b. Electrons which move freely through a solid metal are referred to as free electrons.

c. Materials which have many free electrons are good electrical conductors, while materials which have very few electrons are poor electrical conductors. These poor electrical conductors are called insulators.

d. Since all materials conduct to some extent, there is no sharp dividing line between conductors and insulators. The terms, conductor and insulator, are purely relative.

e. When an atom loses an electron, there is no longer an electrical balance. The atom thus assumes a positive charge, since there are now more protons in the nucleus than there are electrons in the orbits.

f. An atom which has lost an electron becomes a positive ion, and an atom which acquires an excess electron becomes a negative ion.

4. Current.

a. An electric current may be defined as the movement of negative charges (electrons) through a conductor.

b. If an outside influence forces an excess of electrons into a conductor so that there are more electrons than there are protons in the conductor, the conductor becomes negatively charged.

c. If an outside influence removes free electrons from a conductor so that there are more protons than electrons in the conductor, the conductor becomes positively charged.

d. The influence that is normally used to cause a movement of electrons in a conductor is called electromotive force.

e. An atom which has lost a free electron will have a positive charge, and this atom will tend to attract other free electrons because unlike charges attract one another.

f. Free electrons repel one another because like charges repel one another.

g. Though all electrons have the same amount of negative charge, the charge on a single electron is too small for practical use as a unit of measurement; therefore, the coulomb, a larger unit of charge, is used.

h. This practical unit of measurement, the coulomb, is the combined charge of 6.28×10^{18} electrons.

i. The symbol for charge is q.

j. The ampere is the unit of current flow.

k. One ampere of current is flowing in a circuit when 6.28×10^{18} electrons pass a given point per second.

l. The symbol for current is I.

5. Electromotive Force.

a. The force generally used to cause free electrons to move through a conductor is called electromotive force.

b. The symbol for electromotive force is E or emf.

c. The unit of electromotive force is the volt.

d. One volt is the amount of pressure required to force current at the rate of one ampere to flow through one ohm of resistance.

6. Resistance.

a. Since there are no perfect conductors, all conductors offer some resistance to the flow of current.

b. Resistance to current flow in a conductor is similar to the frictional resistance that water encounters when flowing through a pipe.

c. The symbol for resistance is R.

d. The unit of resistance is the <u>ohm</u>.

e. The symbol for ohm is Ω (omega).

f. The schematic symbol for a resistance is -\/\/\/-. When the resistance is inserted in a circuit, it is called a resistor.

g. The resistance of a conductor depends on the kind, length, cross-sectional area, and temperature of the material. In practical applications, temperature is neglected.

7. <u>Electrical Power</u>.

a. Power is the <u>rate</u> at which energy is supplied to a resistor or other energy-consuming device.

b. Power does <u>not</u> represent an <u>amount</u> of energy supplied.

c. The unit of power is the <u>watt</u>.

d. The symbol for power is P.

8. <u>Common Sources of Electrical Energy</u>.

a. Batteries or electrical cells.

1) Primary <u>cells</u> store chemical energy which may be converted to electrical energy when the cells are connected to an electrical circuit. Primary cells are discarded when exhausted and new cells installed. Flashlight cells are an example of primary cells.

2) Secondary cells store energy in chemical form much the same as primary cells. Secondary cells may be recharged when exhausted, however, by connecting them to a source of power. Examples of secondary cells are found in automobile batteries. In this case, the battery is recharged by the automobile generator.

3) The schematic symbol for a battery is shown in diagram 5. The longer lines of the symbol indicate the positive terminals and the shorter lines indicate the negative terminals.

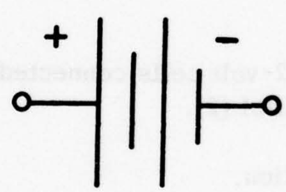


Diagram 5. Battery symbol.

4) A <u>battery</u> consists of two or more cells connected so that all cells contribute to the total power output (diag 6).

5) Cells may be connected in series to produce a higher electromotive force which is the sum of the emf of each cell.

6) When the cells are connected in parallel (assuming that all cells have the same emf), the voltage across the network will be equal to the voltage of any one cell. The current-carrying capability of the parallel-connected cells is the sum of the current-carrying capabilities of the individual cells (diag 6).

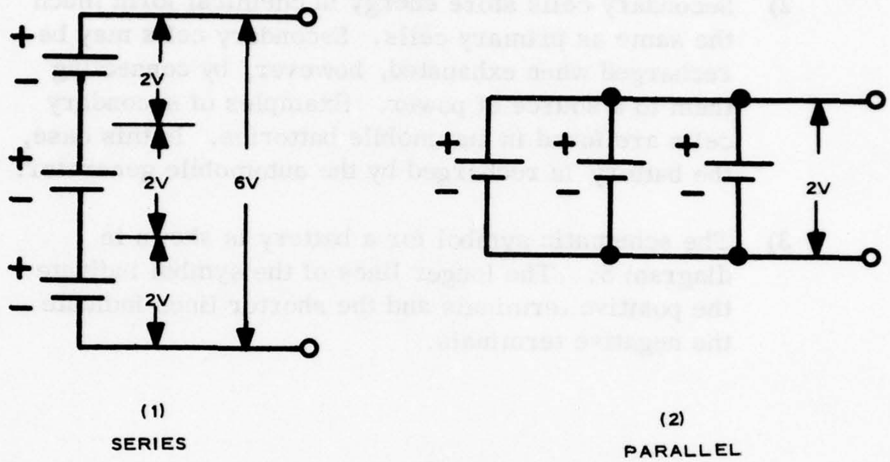


Diagram 6. Three 2-volt cells connected in series (1) and in parallel (2).

b. Magnetic induction.

1) Electromotive force may be induced in a conductor by forcing the conductor to move through a magnetic field in a direction perpendicular to the direction of the magnetic field as shown in diagram 7.

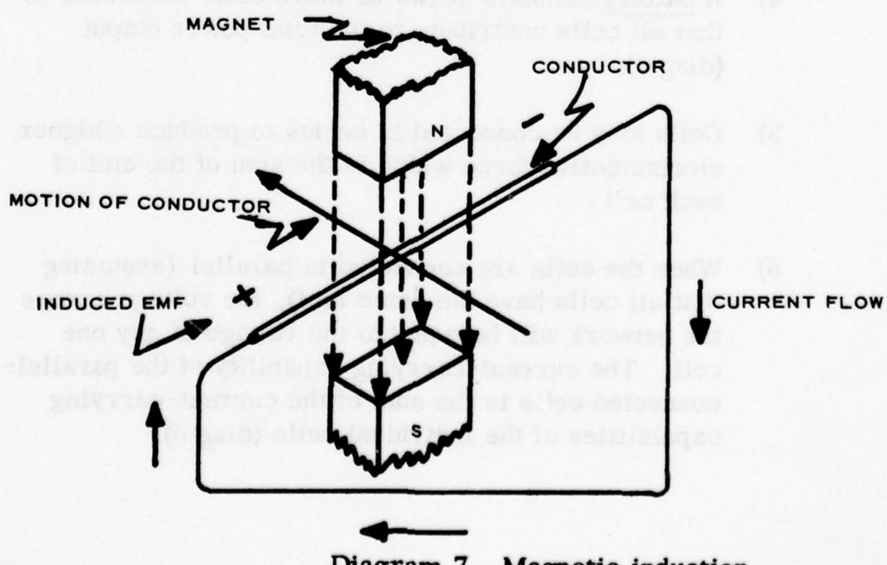


Diagram 7. Magnetic induction.

2) Magnetic induction is the most practical method of producing great amounts of electrical power. The machines which produce power in this manner are called generators.

3) A generator converts mechanical power into electrical power.

SUMMARY:

1. An atom of any element consists of protons and neutrons in the nucleus and of orbital electrons.

2. The electron has a negative charge and the proton a positive charge.

3. Like charges repel, and unlike charges attract.

4. Conductors are materials which have many free electrons.

5. Insulators have very few free electrons.

6. An electric current is a movement of free electrons through a conductor.

7. The symbol of current is I.

8. The unit of current is the ampere.

9. The force utilized to produce an electric current is electromotive force.

10. The symbol for electromotive force is E.

11. The unit of electromotive force is the volt.

12. Resistance is the opposition offered by a conductor to the flow of current.

13. The symbol for resistance is R.

14. The unit of resistance is the ohm.

15. The symbol for ohm is Ω (omega).

16. Power is the rate at which energy is supplied to a resistor or other energy-consuming device.

17. The most practical sources of electromotive force are chemical reaction and magnetic induction.

18. Primary and secondary cells are the common chemical sources of electromotive force.

19. Cells store chemical energy. When connected to an electric circuit, cells convert their chemical energy into electrical energy.

20. A battery consists of two or more cells connected in such a way that each cell contributes to the total power output.

21. An electromotive force is induced in a conductor when the conductor is moved through a magnetic field in a direction that is perpendicular to the direction of the magnetic field.

22. Magnetic induction is the most practical method of producing large amounts of electrical energy.

23. Generators, which use magnetic induction to produce electromotive force, convert mechanical power into electrical power.

LESSON PLAN

ELECTRICAL COMPONENTS AND SYMBOLS

OBJECTIVE:

To acquaint the student with the physical appearances and schematic symbols of electronic components.

INTRODUCTION:

The shape, size, or physical construction of electronic components may affect their power rating, voltage rating, or frequency rating. Therefore, it is important for the student to have such relationships explained by the instructor.

PRESENTATION:

1. The entire lesson will consist of a demonstration by the instructor.

> INSTRUCTOR'S NOTE: As each component listed below is shown to the students, explain the relationship between size, power rating, voltage rating, frequency, or any other characteristic. As each component is shown, put the schematic symbol for that component on the chalkboard.

2. Components to be shown.

   a. Resistors.

      1) Low-wattage, color-coded.

      2) High-wattage, ceramic.

      3) Potentiometer.

b. Capacitors.

1) Mica, color-coded.

2) Ceramic, color-coded.

3) Electrolytic.

4) Oil-filled, filter.

5) Variable.

c. Inductors.

1) Air-core, rf choke.

2) Air-core, rf tuning.

3) Iron-core, filter-choke.

d. Transformers.

1) Air-core, if.

2) Iron-core, power.

e. Diodes.

1) Vacuum tube.

2) Selenium.

3) Germanium.

f. Amplifier vacuum tubes.

1) Miniature triode.

2) Miniature pentode.

3) Octal triode.

4) Octal pentode.

g. <u>Classroom console</u>.

1) Voltmeter-ammeter.

2) Oscilloscope.

3) Power supply.

4) Audio oscillator.

5) Electronic switch.

6) Test leads.

LESSON PLAN

COLOR CODE

OBJECTIVE:

To explain:

1. The necessity for, and the convenience of, color codes;

2. The relationship between numerical digits and colors used in coding;

3. How to recognize the two types of color coding on resistors and the two general types of color coding on capacitors; and

4. The significance of tolerance.

INTRODUCTION:

The system of color coding for currently used resistors and capacitors reduces the time required for a technician to locate components wired into a circuit. Color coding makes it possible to read the values of resistors and capacitors quickly and easily from a distance and from any angle. Color coding is not a necessity, but it is a convenience that greatly reduces the working time of the technician.

PRESENTATION:

1. Relation of Colors and Numerical Digits.

   a. Listed below are the colors and the digits they represent.

      1) Black - 0

      2) Brown - 1

      3) Red - 2

4) Orange - 3

5) Yellow - 4

6) Green - 5

7) Blue - 6

8) Violet - 7

9) Gray - 8

10) White - 9

b. The sequence of colors may be easily remembered by memorizing the two sentences given below.

1) Black bruins raid our yellow grain.

(Black)	(Brown)	(Red)	(Orange)	(Yellow)	(Green)
0	1	2	3	4	5

2) Blue violets grow wild.

(Blue)	(Violet)	(Gray)	(White)
6	7	8	9

2. Color Coding of Resistors (General).

a. Color-coded resistors are marked with colors to indicate two significant figures: a multiplier and a tolerance percentage.

b. Precision resistors which have a tolerance of one percent or less are not color-coded. The values are printed on the body of the resistors.

c. Color codes on axial-lead resistors (diag 8) are applied as bands of color circling the body of the resistor.

d. Color codes on radial-lead resistors (diag 8) are applied to the body, the ends, and as a dot or band at the center of the body.

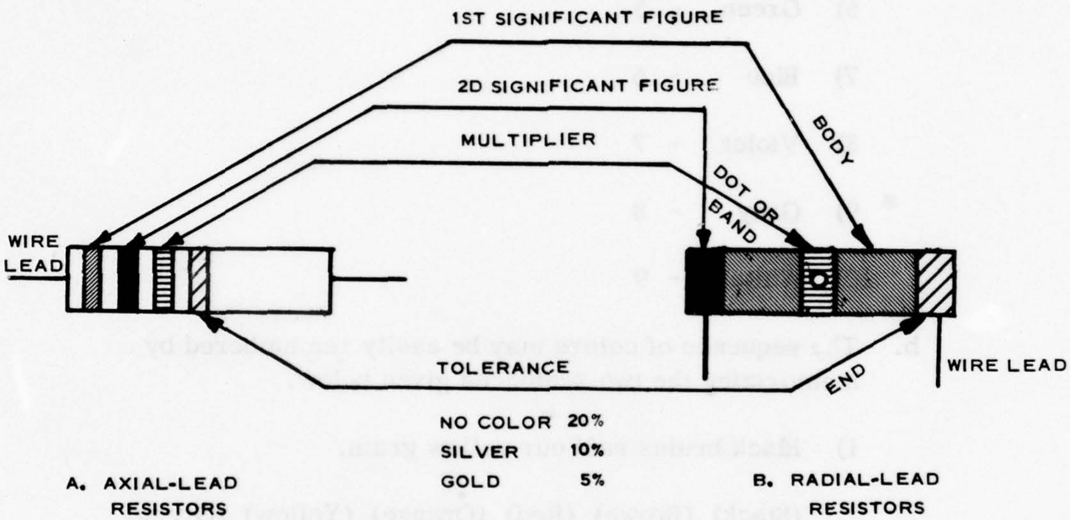


Diagram 8. Color-coded resistors.

e. All color-coded resistors have two colors to indicate two significant figures and one color to indicate the number of zeros to follow the significant figure.

1) If there is <u>no</u> fourth color, the resistance value is within 20 percent of the value indicated by the three colors.

a) If the fourth color is <u>silver</u>, the actual value is within 10 percent.

b) If the fourth color is <u>gold</u>, the actual value is within five percent of the indicated value.

2) Silver and gold are the only colors used for the fourth color band.

3. <u>Axial-Lead Resistors</u>.

a. When translating the color bands into figures, the band nearest one end of the resistor is the first significant figure, the next band is the second significant figure, and the third band indicates the number of zeros to follow the two significant figures. The fourth band indicates a tolerance of 10 percent (silver) or 5 percent (gold). If there is no fourth band, the tolerance is 20 percent.

b. Diagram 9 shows six examples of color coding on axial-lead resistors. The resistors are lettered from A through F, and the values and tolerances indicated by the colors are as follows:

1) A-26,000 ohms, 20% tolerance;

2) B-530,000 ohms, 20% tolerance;

3) C-3,400 ohms, 5% tolerance;

4) D-1,200,000 ohms, 10% tolerance;

5) E-80 ohms, 20% tolerance; and

6) F-4,700,000 ohms, 5% tolerance.

4. <u>Radial-Lead Resistors</u>.

a. The body color of radial-lead resistors indicates the first significant figure, the color of one end indicates the second significant figure, and the dot or band at the center of the body indicates the number of zeros to follow the two significant figures. The other end of the resistor will be gold or silver to indicate 5 percent or 10 percent tolerance.

b. Diagram 10 shows six examples of radial-lead, color-coded resistors. The indicated values of the resistors are as follows:

1) (1)-6,300 ohms, 5% tolerance;

2) (2) -1,400,000 ohms, 5% tolerance;

3) (3) -33,000 ohms, 20% tolerance;

4) (4) -280 ohms, 20% tolerance;

5) (5) -92 ohms, 5% tolerance; and

6) (6) -400,000 ohms, 20% tolerance.

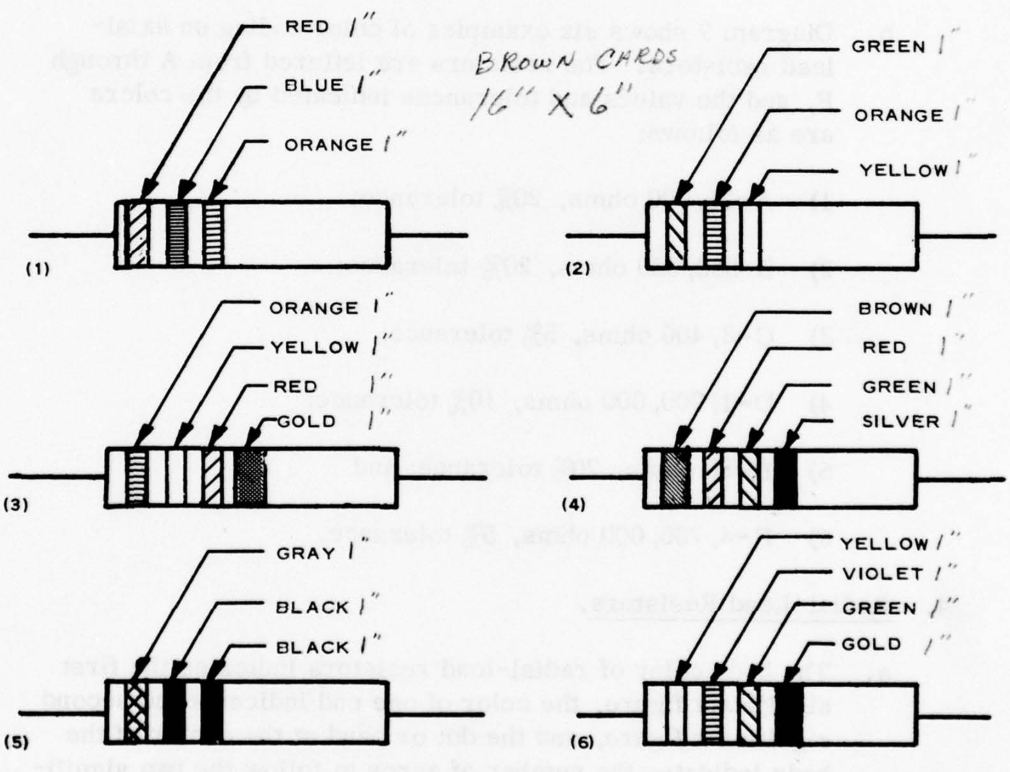


Diagram 9. Examples of color-coded resistors.

5. <u>Color Coding of Capacitors (General).</u>

There are two general methods of color coding fixed, paper, or mica-insulated capacitors: the three-dot system and the six-dot system. Both systems will be explained below. All capacitors which use color coding to indicate values will have their value given in micromicrofarads (μμf).

16" X 6" Cards

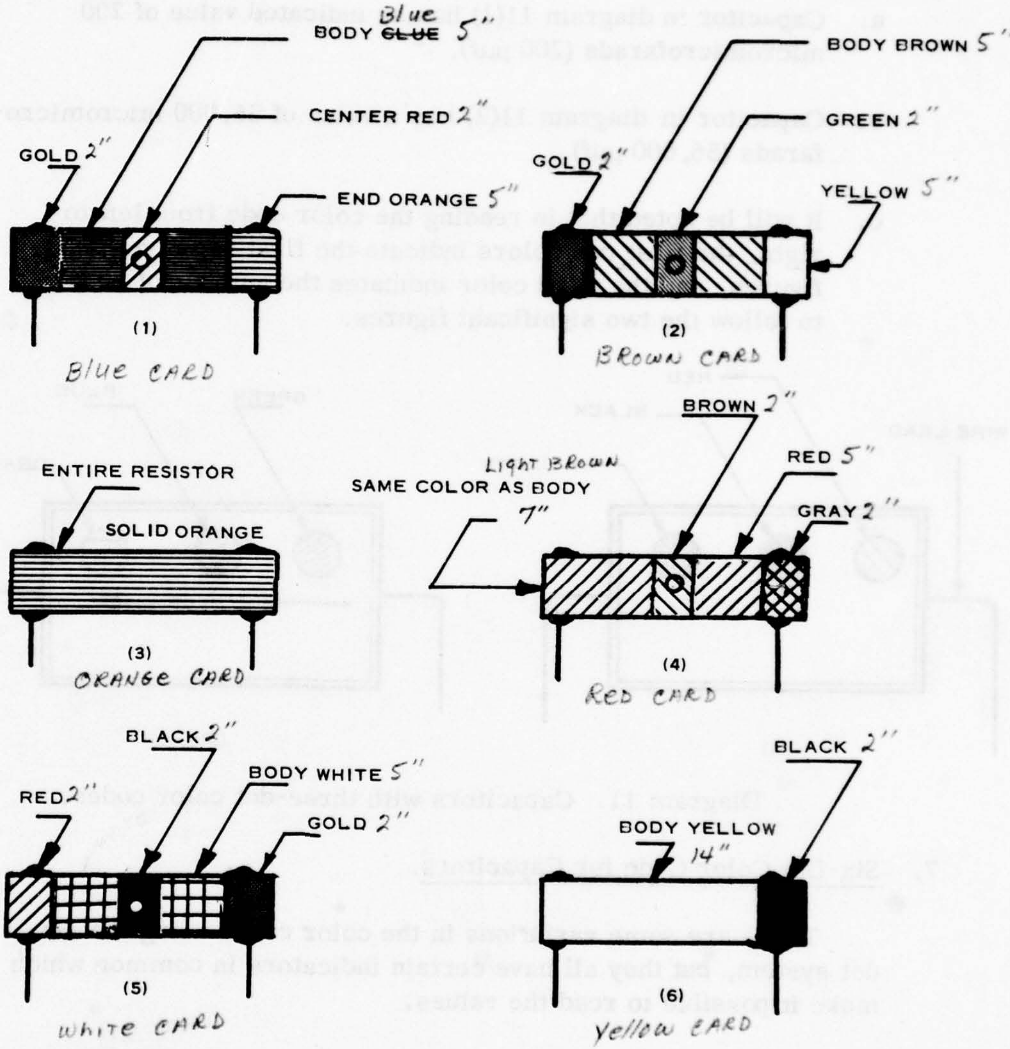


Diagram 10. Radial-lead resistors.

6. Three-Dot Color Code for Capacitors.

The color code of the three-dot system is always read in the direction of the arrow. If no arrow is present, the capacitor is held in the proper position to read the printed matter, and the color code can then be read from left to right. Two examples of capacitors using the three-dot system are shown in diagram 11.

a. Capacitor in diagram 11(1) has an indicated value of 200 micromicrofarads (200 $\mu\mu f$).

b. Capacitor in diagram 11(2) has a value of 56, 000 micromicrofarads (56, 000 $\mu\mu f$).

c. It will be noted that in reading the color code from left to right, the first two colors indicate the first two significant figures, and the third color indicates the number of zeros to follow the two significant figures.

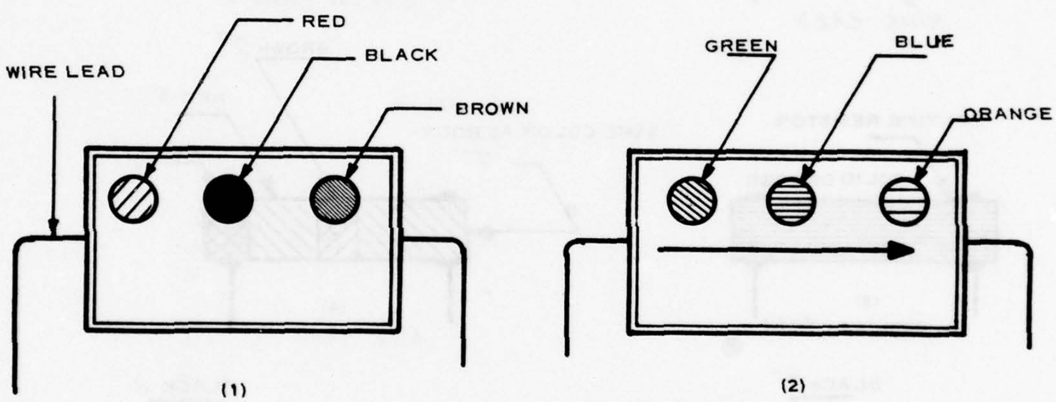


Diagram 11. Capacitors with three-dot color codes.

7. Six-Dot Color Code for Capacitors.

There are some variations in the color codes using the six-dot system, but they all have certain indicators in common which make it possible to read the values.

a. To read the six-dot system of color coding, the capacitor must be held so that the arrow, if present, points from left to right. If there is no arrow, the printed matter is held in proper position for reading.

b. Some capacitors have three significant figures and multiplier (number of zeros to follow), and others have two significant figures and a multiplier. The following rules can be used in reading either system (diag 12).

1) The lower left hand dot is ignored.

2) The dot at the center of the bottom row is always the tolerance: no color, 20 percent; silver, 10 percent; gold, 5 percent.

3) The lower right hand dot is always the multiplier (number of zeros to be added to the significant figures).

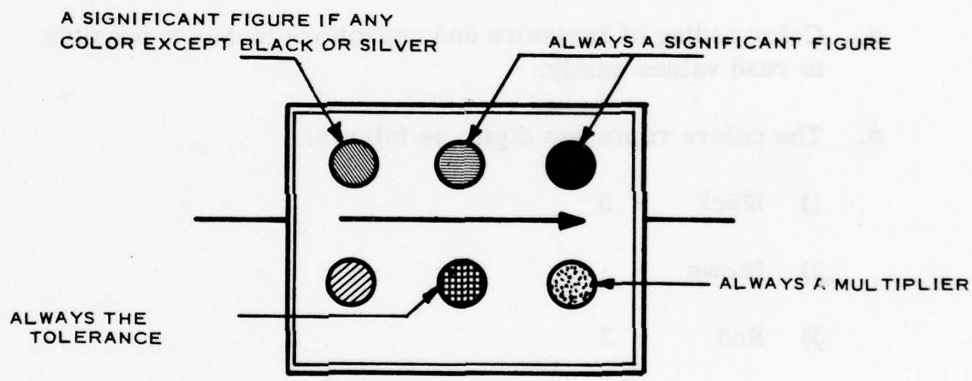


Diagram 12. Six-dot color code for capacitors.

4) If the upper left hand dot is any color other than black or silver, it becomes the first figure of three significant figures, and the next two dots in the upper row become the second and third significant figures.

5) If the upper left hand dot is black or silver, the center dot in the upper row becomes the first significant figure, and the upper right hand dot becomes the second significant figure.

c. Diagram 13 shows six capacitors using the six-dot color code. The values of the capacitors from (1) through (6) are as follows:

1) A-251 μμf, 5 % tolerance;

2) B–260 μμf, 20% tolerance;

3) C–780 μμf, 20% tolerance;

4) D–667 μμf, 5% tolerance;

5) E–3, 900 μμf, 10% tolerance; and

6) F–450 μμf, 20% tolerance.

8. <u>Summary of the Color Code</u>.

a. Color coding of resistors and capacitors makes it possible to read values easily.

b. The colors represent digits as follows:

1) Black - 0

2) Brown - 1

3) Red - 2

4) Orange - 3

5) Yellow - 4

6) Green - 5

7) Blue - 6

8) Violet - 7

9) Gray - 8

10) White - 9

c. Axial-lead resistors are color coded by bands of color around the body of the resistors.

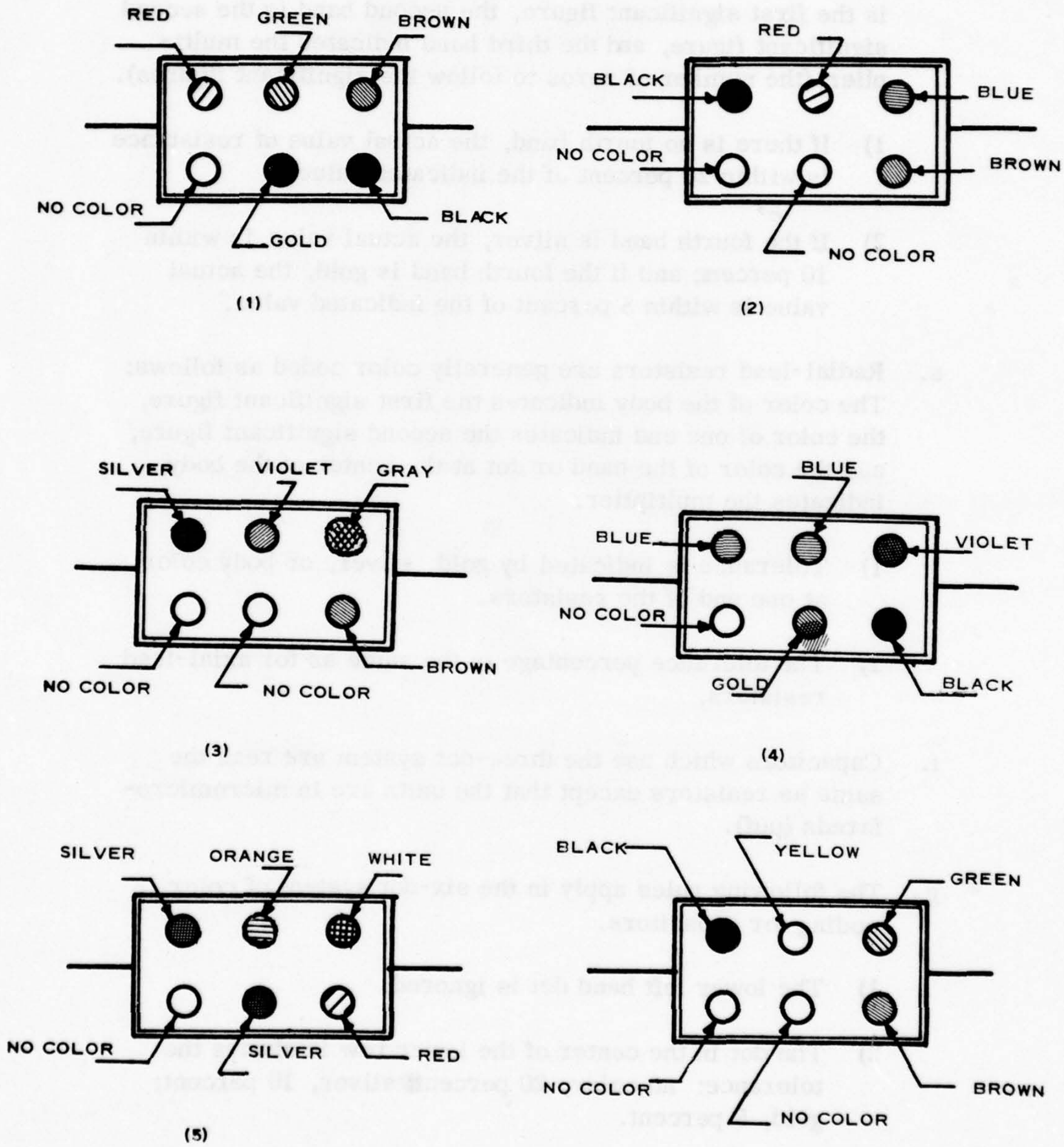


Diagram 13. Examples of six-dot color code.

d. On axial-lead resistors, the color band nearest one end is the first significant figure, the second band is the second significant figure, and the third band indicates the multiplier (the number of zeros to follow the significant figures).

   1) If there is no fourth band, the actual value of resistance is within 20 percent of the indicated value.

   2) If the fourth band is silver, the actual value is within 10 percent; and if the fourth band is gold, the actual value is within 5 percent of the indicated value.

e. Radial-lead resistors are generally color coded as follows: The color of the body indicates the first significant figure, the color of one end indicates the second significant figure, and the color of the band or dot at the center of the body indicates the multiplier.

   1) Tolerance is indicated by gold, silver, or body color at one end of the resistors.

   2) The tolerance percentage is the same as for axial-lead resistors.

f. Capacitors which use the three-dot system are read the same as resistors except that the units are in micromicrofarads (μμf).

g. The following rules apply in the six-dot system of color coding for capacitors.

   1) The lower left hand dot is ignored.

   2) The dot in the center of the lower row is always the tolerance: no color, 20 percent; silver, 10 percent; gold, 5 percent.

   3) The lower right hand dot is always the multiplier.

   4) The upper left hand dot is ignored if it is black or silver, in which case the top center dot and the upper

right hand dot become the first and second significant figures of the indicated value.

5) If the upper left hand dot is any other color than black or silver, that dot becomes the first figure of three significant figures, the upper center and the upper right hand dots being the second and third significant figures.

CLASSROOM EXERCISE:

1. Equipment Needed. Resistor-capacitor board.

2. Procedure. Resistor and capacitor color code.

a. In table 2a, list the correct colors opposite the numbers.

b. In table 2b, list the correct color opposite the present tolerance as given by the color code.

Table 2

RESISTOR AND CAPACITOR COLOR CODE

a-Numbers

Number	Color	Number	Color
0	________	5	________
1	________	6	________
2	________	7	________
3	________	8	________
4	________	9	________

b-Tolerance

Tolerance	Color
5 percent	________
10 percent	________
20 percent	________

3) Observe the resistors on the resistor-capacitor board. List the colors, and determine the numerical value and tolerance of each. Record the data in table 3.

Table 3
VALUES OF RESISTORS

Resistor	Colors	Ohms	Percent Tolerance
1			
2			
3			
4			
5			
6			
7			
8			

4) From the tolerance values listed for resistors 2 and 8, what maximum and what minimum values of resistance could be expected?

R2 ____________ ____________ R8 ____________ ____________
max min max min

5) Observe the capacitors on the resistor-capacitor board. List the colors and determine the numerical value and tolerance of each. Record the data in table 4.

Table 4
VALUES OF CAPACITORS

Capacitors	Colors	Capacitance	Percent Tolerance
1			
2			
3			
4			
5			
6			
7			
8			

6) List the colors opposite the following resistors and capacitors according to the color code.

Table 5
PROBLEMS ON RESISTOR AND CAPACITOR COLOR CODE

Resistor and Capacitor	Colors
3.9 meg (±20%)	__________
2 meg	__________
240 K	__________
350 ohms (±10%)	__________
0.1 μf	__________
1,500 μμf	__________
240 uf	__________
0.05 uf	__________

IF-3

SUMMARY:

1. The color code is a standard accepted method for identifying the values of resistors and capacitors.
2. The tolerance of resistors and capacitors is also indicated by color codes.

LESSON PLAN

MAGNETISM

OBJECTIVE:

To demonstrate and explain:

1. The importance and uses of magnetic phenomena,

2. Magnetic and nonmagnetic materials,

3. The magnetic fields existing around permanent magnets,

4. The magnetic field existing around a wire or coil of wire through which current is flowing, and

5. The laws of magnetic attraction and repulsion.

INTRODUCTION:

1. The principles of magnetism are widely used in the operation of generators, motors, measuring instruments, transformers, radio and radar components, and other electrical devices. Consequently, an understanding of the basic principles of magnetism is essential before the operation of electrical devices may be understood.

2. In addition to the magnetism utilized in man-made equipment, magnetic poles and fields of force exist in a natural state. The most commonly known example is the North and South Magnetic Poles of the earth and their connecting magnetic field. Everyone has seen the needle of a compass swing toward the north. This pointing of the compass needle in a northerly direction is caused by the attraction between the North Magnetic Pole of the needle and the South Magnetic Pole of the earth which is located near the geographic North Pole.

3. It is not known exactly why a magnet exerts a pull on a piece of iron even though the two may be separated by a material such as air, wood, or glass. An attracting force on the iron does exist, however, and is caused by a magnetic field emanating from the magnet. Although this field can neither be seen nor felt, experiments can be performed which clearly demonstrate its existence, shape, and variation of intensity along the field-space pattern.

4. Magnetism and electricity are closely associated. When electrons flow through a conductor, a magnetic field is produced around the wire.

5. Magnetism is inseparably interrelated with electricity. Consequently, as electrical machines have been rapidly invented and manufactured for everyday operation, the use of magnetism has been expanded correspondingly.

PRESENTATION:

> INSTRUCTOR'S NOTE: Demonstration equipment required: 2 magnetized compass needles with 1 pointed pivot, magnetron magnet, 1 bar magnet, round iron bar, large wire loop with holder, 1 solenoid with terminals, variac, dc power supply, wire connectors, bottle of iron filings, 12" x 12" sheet of white cardboard.

1. Materials which can be attracted by a magnet are called magnetic. Examples are iron, nickel, cobalt, and some alloys. Alloys, such as alnico, an alloy of aluminum, nickel, and cobalt are mainly used in high-grade permanent magnets. Aluminum is nonmagnetic, and nickel and cobalt in their separate states have poor magnetic qualities. The combination of the three, however, makes excellent permanent magnet material.

2. Nonmagnetic materials are those which cannot be magnetized. Examples are aluminum, copper, silver, wood, glass, liquids, and gases.

3. The molecules of iron or steel seem to be minute magnets which are arranged haphazardly in the unmagnetized state. When a magnetizing force is applied to a bar of iron or steel, the molecules become arranged in a definite pattern with their north and south poles pointing in opposite directions. The sum of the individual molecular magnets acting in the same direction establishes the north and south poles of such a bar magnet. These changes in molecular arrangement, caused by the magnetizing force, are illustrated in diagram 14.

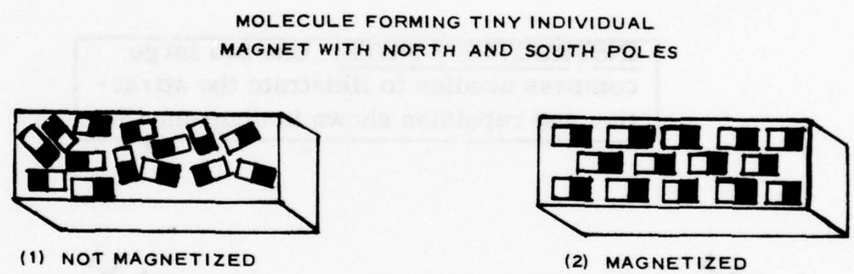


Diagram 14. Rearrangement of molecules in a magnetic material when a magnetizing force is applied.

4. When a material is easy to magnetize, it is said to have high permeability. Soft iron, being relatively easy to magnetize, is an example. Steel, being harder to magnetize than soft iron, has a relatively low permeability.

5. The ability of a magnetic material to retain its magnetism after the magnetizing force has been removed is called its retentivity. The retentivity of steel and alloys which form permanent magnets is much higher than that of soft iron. Alnico has very high retentivity.

6. The amount of magnetism remaining in a material after the magnetizing force has been removed is called its residual magnetism.

7. If the south pole of a magnet is brought near the south pole of a suspended magnet (diag 15), the suspended magnet will turn away. The same result occurs when the north poles are used. It can be seen, then, that like magnetic poles repel. If a south pole is brought near the north pole of a suspended magnet, the suspended magnet moves toward the second magnet. The same movement would result from bringing a north pole near the south pole of the suspended magnet, showing that unlike magnetic poles attract. The law of magnets may be stated as follows: Like poles repel; unlike poles attract.

INSTRUCTOR'S NOTE: Use two large compass needles to illustrate the attraction and repulsion shown in diagram 15.

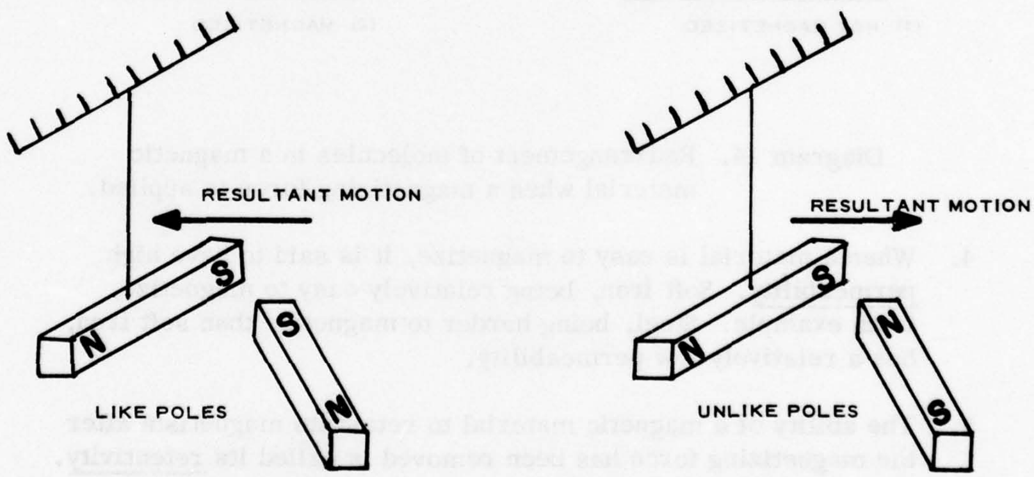


Diagram 15. Like poles repel; unlike poles attract.

8. The region of influence around a bar magnet is called the magnetic field, and the field is assumed to have a direction of north to south outside of the magnet. Inside the magnet the direction of the magnetic field is from south to north (diag 16). The magnetic field may be referred to as magnetic flux, or lines of force.

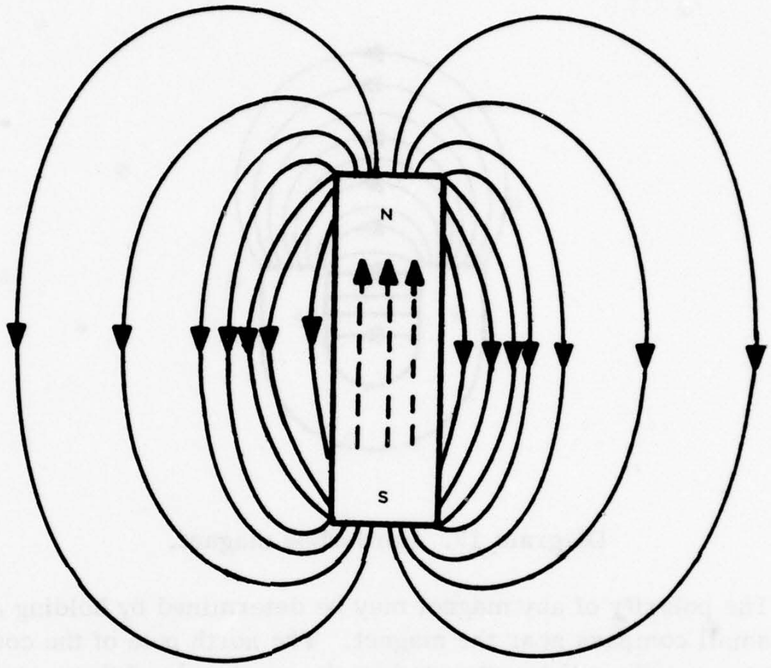


Diagram 16. Magnetic field around a bar magnet.

9. A permanent magnet formed in the shape of a horseshoe reduces the length of path for that part of the magnetic flux that passes through the air. The horseshoe shape of the magnet not only reduces the air path for magnetic flux, which permits a greater amount of magnetic flux to be produced, but also greatly increases the flux density in the short air gap between the magnet poles (diag 17).

INSTRUCTOR'S NOTE: Illustrate the magnetic field of the large radar magnet by sprinkling iron filings over a cardboard held beside the magnet.

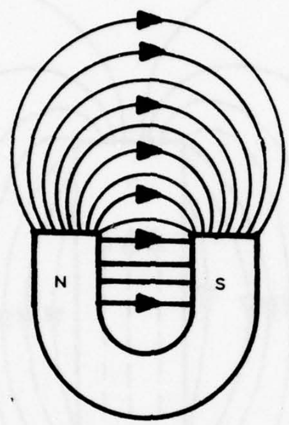


Diagram 17. Horseshoe magnet.

10. The polarity of any magnet may be determined by holding a small compass near the magnet. The north pole of the compass needle will be attracted by the south pole of the magnet.

> INSTRUCTOR'S NOTE: Illustrate the means of locating the North and South Poles of the large radar magnet by means of the large compass needle.

11. The magnetic lines of force have the following properties:

    a. Lines of force never cross one another,

    b. Lines of force which have the same direction behave as though they repel one another laterally,

    c. Lines of force behave as though they were under tension and try to become as short as possible subject to conditions in paragraphs a and b above,

d. The magnetic field exists in the entire space surrounding a magnet, and

e. There are no known magnetic insulators.

INSTRUCTOR'S NOTE: Explain that magnetic shielding is accomplished by surrounding an object by a good magnetic conductor such as soft iron.

12. Electron flow through a wire conductor will produce a magnetic field which circles the wire. The magnetic field produced by the electron flow is identical to the magnetic field produced by a permanent magnet. The direction of the magnetic field surrounding the wire is shown in diagram 18.

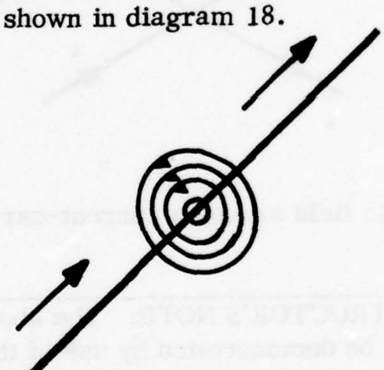


Diagram 18. Magnetic field around a current-carrying conductor.

13. A simple rule (relating the direction of current or electron flow and the direction of field established) called the left hand rule for a conductor, is: Imagine grasping the conductor in the left hand with the thumb pointing in the direction of the electron flow; the fingers then point in the direction of the field around the conductor.

14. If the straight conductor in diagram 18 is bent into the form of a two-turn loop the magnetic field surrounds the turns as shown in diagram 19, and the coil becomes an electromagnet which has North and South poles. If a compass needle were brought close to the near side of the coil, the South Pole of the needle would be attracted to the coil opening nearest the reader. If the compass were placed on the back side of the coil, the North Pole of the needle would be attracted toward the back opening of the coil.

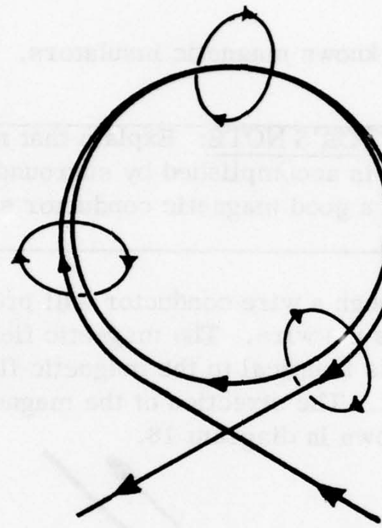


Diagram 19. Magnetic field around a current-carrying coil of wire.

> INSTRUCTOR'S NOTE: The above phenomenon will be demonstrated by use of the demonstration loop, 12v dc power supply, variac, and large compass needle.

15. When a current-carrying wire is wound into a coil of many turns, as shown in diagram 20, the electromagnet produces a more magnetic flux (more intense magnetic field); and the attraction or repulsion of other magnets becomes more effective. If an iron core is placed inside of the coil, the magnetic flux becomes much more dense, and the magnetic effects are greatly increased.

> INSTRUCTOR'S NOTE: Illustrate the above phenomena by means of a solenoid, dc power supply, variac, iron bars, and large compass.

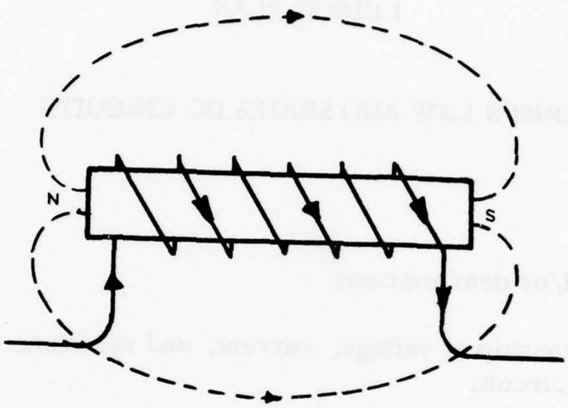


Diagram 20. Magnetic field around a current-carrying wire wound into a coil.

16. The left hand rule for a conductor can be modified to apply to a coil. The *left hand rule for a coil* is: Imagine grasping the coil in the left hand with the fingers pointing in the direction of electron flow around the axis of the coil; the thumb then points toward the north pole of the coil.

LESSON PLAN

OHM'S LAW AND SERIES DC CIRCUITS

OBJECTIVE:

To explain and/or demonstrate:

1. The relationship of voltage, current, and resistance in any resistive circuit;
2. The meaning of the term "direct current";
3. How to apply Ohm's law to any resistive circuit or any part of any resistive circuit;
4. The meaning of the term "voltage drop";
5. How to apply Kirchhoff's voltage law to a series circuit; and
6. How to determine the power supplied to a circuit, and how to determine the power dissipated by any part of a series circuit.

INTRODUCTION:

1. The relationships of current, voltage, and resistance in both simple and complex electronic circuits are of great importance. Ohm's law and Kirchhoff's voltage law express these relationships.

2. Definitions, symbols, and conversion of units.

   a. Series Circuit.

      1) A series circuit is a circuit which supplies energy to a number of devices in series.

      2) The same current passes through each device in completing its path from the negative to the positive side of the voltage source (diag 21).

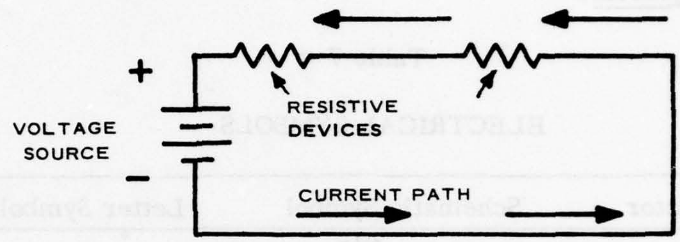


Diagram 21. Series circuit.

b. Direct Current.

1) Current is called direct current (dc) 3/ when the electrons flow in one direction.

2) Voltage sources for direct current are batteries, dc generators, and rectifiers.

3) In diagram 21, the arrows indicate dc flow.

c. Electrical Terms and Units.

Table 6
ELECTRICAL TERMS AND UNITS

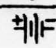
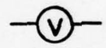
Term	Unit
Voltage (electromotive force)	volt
Current (electron flow)	ampere
Resistance (opposition)	ohm
Power (rate of energy supply)	watt

3/ Direct current is abbreviated DC in Volumes I and VI and abbreviated dc in Volumes II through V.

d. Symbols.

Table 7

ELECTRICAL SYMBOLS

Factor	Schematic Symbol	Letter Symbol
Battery		E
Resistor		R
Ground		Gnd
Voltmeter		V
Ammeter		A

e. Conversion Table.

Table 8

CONVERSION TABLE FOR ELECTRICAL SYMBOLS

Unit	Equals
1 ampere	1,000,000 microamperes
1 ampere	1,000 milliamperes
1 volt	1,000,000 microvolts
1 volt	1,000 millivolts
1 kilovolt	1,000 volts
1 megohm	1,000,000 ohms
1 kilo-ohm	1,000 ohms
1 watt	1,000,000 microwatts
1 watt	1,000 milliwatts
1 kilowatt	1,000 watts
1 milliampere	0.001 ampere

PRESENTATION:

1. In every circuit where there is a movement of electrons, voltage, current, and resistance exist. Ohm's law expresses the relationship of voltage, current, and resistance.

2. Ohm's law.

   a. In an electric circuit, the current in amperes is equal to the electromotive force in volts divided by the resistance in ohms.

   b. The statement may be expressed by the equation,

$$I = \frac{E}{R}. \qquad (1)$$

   c. The equation for Ohm's law indicates that the current varies directly with the pressure and inversely as the resistance.

      1) Diagram 22 illustrates the relationship by comparing a water circuit with an electric circuit.

      2) In comparing the two circuits, it will be noted that if the pump pressure is increased, the flow of water will increase; and if the electromotive force of the battery is increased, the electron flow will increase.

INSTRUCTOR'S NOTE: By means of illustrations on the blackboard, show the students how to use the memory aid for Ohm's law as shown in diagram 23.

      3) If the force exerted by the pump remains constant but the small pipe is decreased in diameter (higher frictional resistance), the water flow is decreased.

      4) Likewise, in the electric circuit, if the battery voltage remains constant while the resistance is increased, the electron flow will decrease.

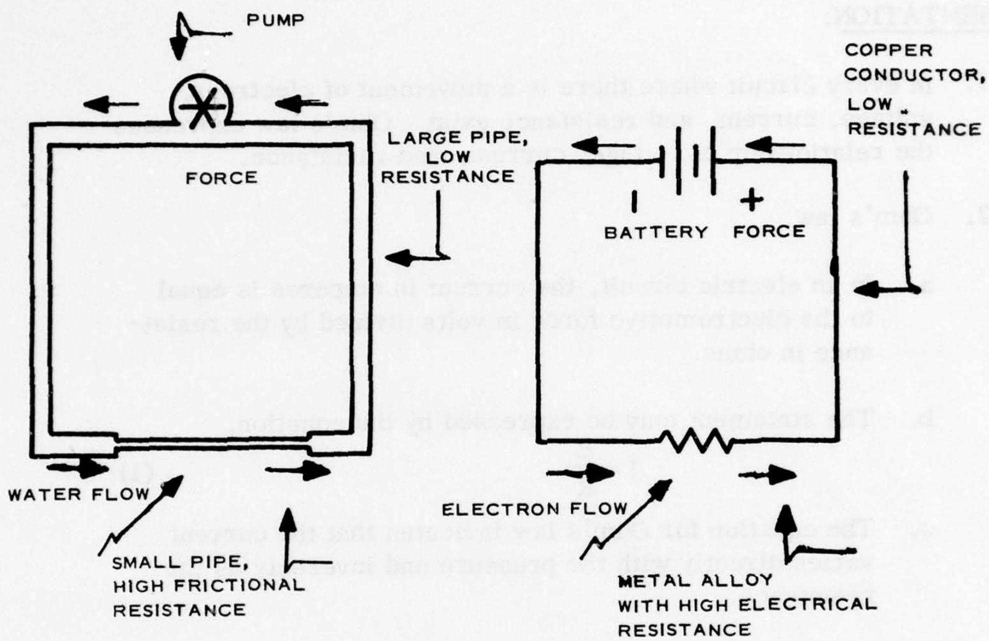


Diagram 22. Comparison of an electric circuit with a water circuit.

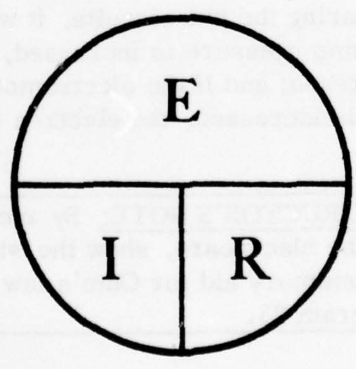


Diagram 23. Ohm's law.

d. Ohm's law is true for any electric circuit or part of a circuit. It may be expressed by any one of three formulas:

1) $I = \frac{E}{R}$: Current equals the voltage divided by the resistance, (1)

2) $R = \frac{E}{I}$: Resistance equals the voltage divided by the current, and (2)

3) E = IR: The voltage is equal to the product of the current and the resistance. (3)

e. The "voltage drop" across any resistor is the voltage difference between the two ends of the resistor. If a battery is connected to a single resistor, the voltage drop will be equal to the applied voltage; but if the circuit consists of two or more resistors in series, the drop across any one resistor will be less than the applied voltage.

f. Diagram 24 shows several circuits which illustrate Ohm's law. In each of the circuits the current must be determined.

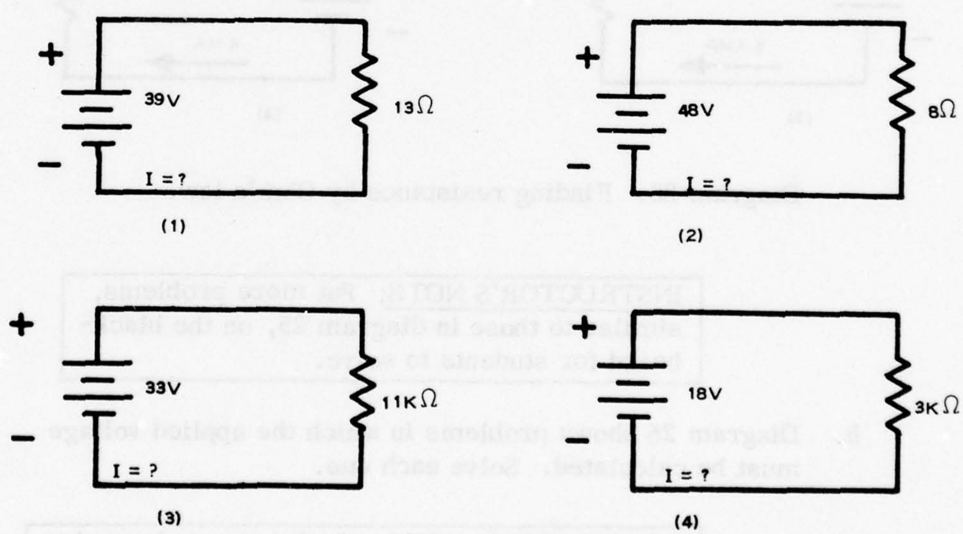


Diagram 24. Finding current by Ohm's law.

INSTRUCTOR'S NOTE: Construct more problems like those in diagram 24 for students to solve. Explain to students that volts divided by kilo-ohms is equal to milliamperes.

g. Diagram 25 shows four circuits in which the resistance is unknown. Solve for the resistance in each.

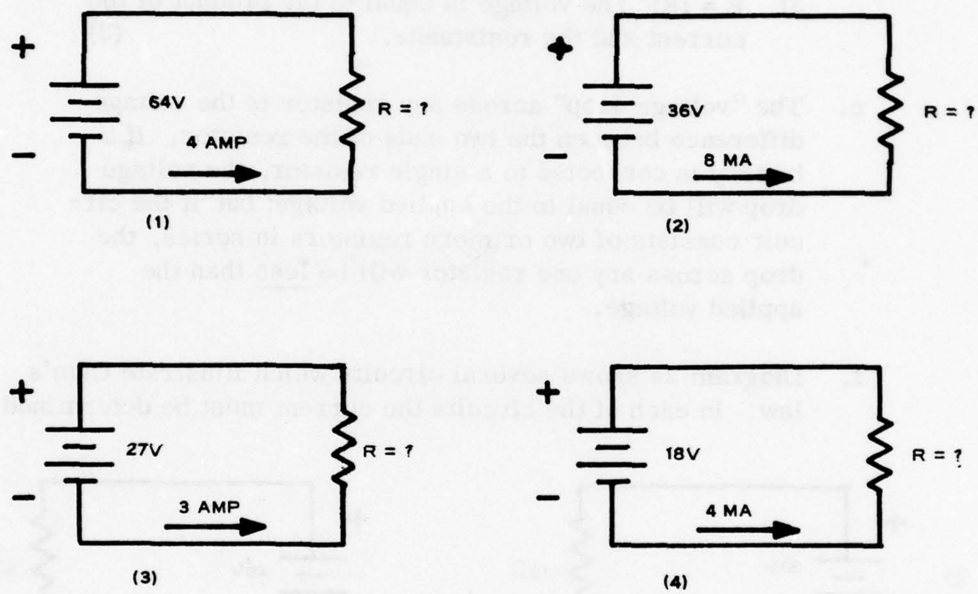


Diagram 25. Finding resistance by Ohm's law.

INSTRUCTOR'S NOTE: Put more problems, similar to those in diagram 25, on the blackboard for students to solve.

h. Diagram 26 shows problems in which the applied voltage must be calculated. Solve each one.

INSTRUCTOR'S NOTE: Explain to students that milliamperes multiplied by kilo-ohms is equal to volts.

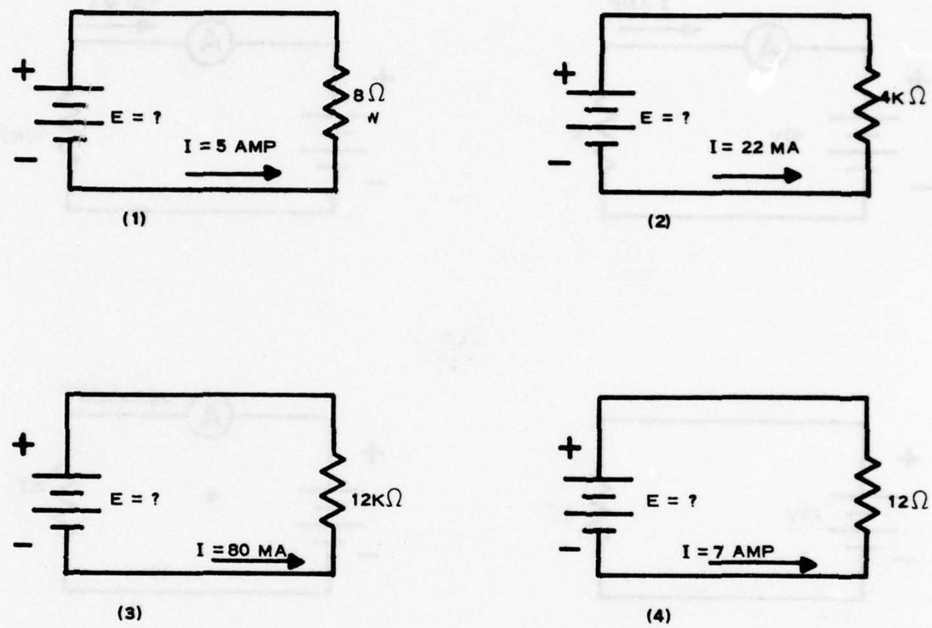


Diagram 26. Finding applied voltage by Ohm's law.

i. The power dissipated by any resistor may be found by any one of three equations:

1) $P = EI$, P = Power in watts. (4)

2) $P = \frac{E^2}{R}$, and E = Voltage across the resistor. (5)

3) $P = I^2R$. I = Current through the resistor in amperes. (6)

R = Resistance in ohms.

j. Diagram 27 shows four circuits in which the power dissipated by a resistor is to be found. The equation used for each circuit should determine the power in terms of the values given in the diagram.

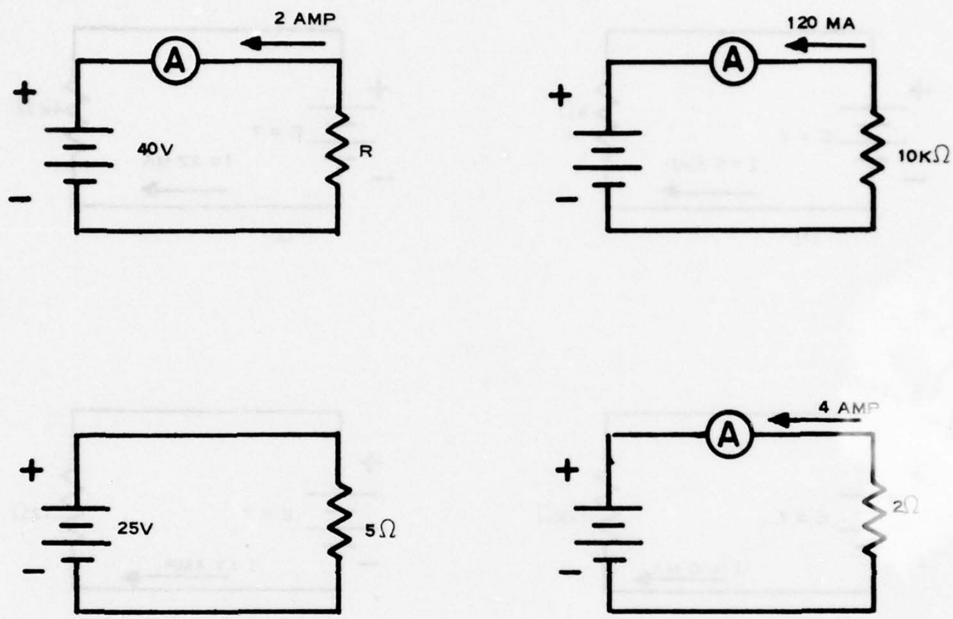
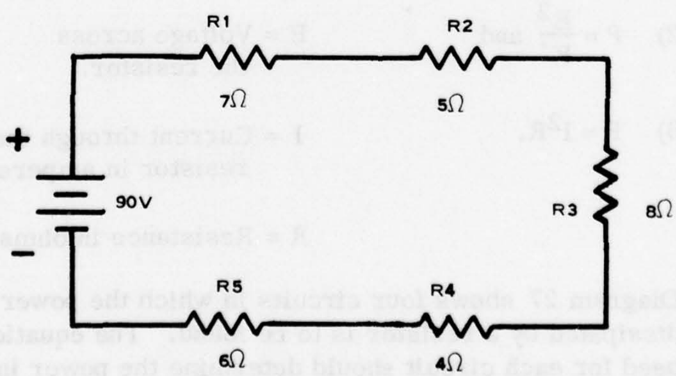


Diagram 27. Simple power problems.

k. When two or more resistors are connected in <u>series</u> the total resistance is equal to the <u>sum</u> of the resistances (diag 28).



$R_t = 7 + 5 + 8 + 4 + 6 = 30$ OHMS.

Diagram 28. Resistance in series.

l. The current that flows in a series circuit is equal to the applied voltage divided by the total resistance R_t of the circuit (diag 28).

1) $I = \frac{E}{R_t} = \frac{90}{30} = 3$ amperes.

2) The current in a series circuit is the same everywhere in the circuit. If three amperes flow through R1, there will be three amperes flowing through R2, R3, R4, and R5 (diag 28).

m. The voltage drop that appears across any resistor is equal to the current in amperes flowing through that resistor multiplied by its resistance value in ohms.

1) In diagram 28, the voltage drop E1 across R1 is equal to 3 (*I*) *times* 7 (*R1*).

$$E1 = I(R1) = 3 \times 7 = 21v.$$

2) E2, the drop across R2, is found by the equation:

$$E2 = I(R2) = 3 \times 5 = 15v.$$

3) The voltage drops across the other resistors will be found in the same way.

a) E3 = 24v

b) E4 = 12v

c) E5 = 18v

3. Kirchhoff's voltage law.

a. The sum of the voltage drops around a series circuit is equal to the applied voltage.

$$E_t = E1 + E2 + E3 \ldots + E_n \qquad (7)$$

$$E_{battery} = E1 + E2 + E3 + E4 + E5$$
$$= 21 + 15 + 24 + 12 + 18 = 90.$$

INSTRUCTOR'S NOTE: In all cases the applied voltage is taken to mean the electrical pressure that is applied across the circuit and may originate in a battery, generator, or resistance.

b. The polarity of the voltage drop across any resistor is always such that the current (electron flow) enters the negative end of the voltage drop (diag 29). It will be noted in diagram 29 that the current leaves the negative terminal of the power supply (battery).

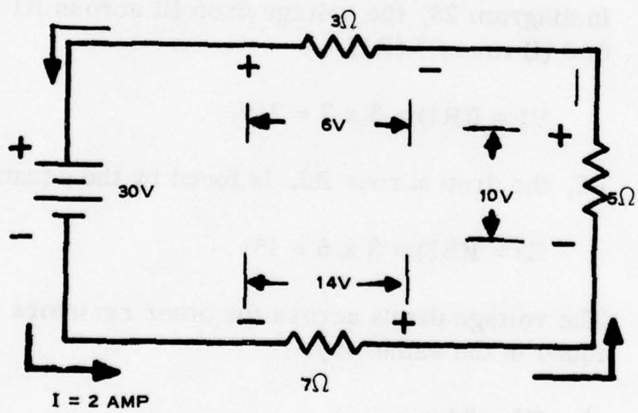


Diagram 29. Polarities of voltage drops.

c. The total power supplied by a battery is equal to the battery voltage multiplied by the battery current.

1) As an example, the battery current in diagram 30 is 3 amperes, while the battery voltage is 75v. The total power P_t is found to be EI = 75 x 3 = 225 watts by equation (4).

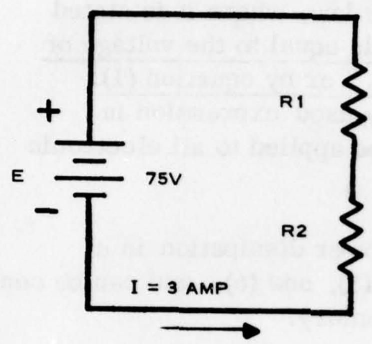


Diagram 30. Series circuit for power calculations.

2) The power P1 dissipated by R1 of diagram 30 is found by equation (6):

$$P1 = I^2(R1) = 3^2 \times 14 = 9 \times 14 = 126 \text{ watts.}$$

(The equation used above is only one of three power equations that can be used, see equations (4), (6).)

3) The power P2 dissipated by R2 of diagram 30 is found by equation (6):

$$P2 = 3^2 \times 11 = 9 \times 11 = 99 \text{ watts.}$$

4) It will be noted that the total power supplied by the battery in diagram 30 (225 watts) is the sum of the power (126 watts and 99 watts) dissipated by R1 and R2. It is always true that the total power supplied by the power source (battery) is equal to the sum of powers dissipated by the individual resistors.

SUMMARY:

1. As in every exact science, the student must first master the various symbols that express the different values and quantities with which he must work. Some of these symbols will be found in the table at the beginning of this chapter.

2. The relationship between voltage, current, and resistance in any dc circuit is expressed by Ohm's law, where it is stated that, "The current in any dc circuit is equal to the voltage of that circuit divided by its resistance," or by equation (1). This formula is the most universally used expression in electronics and variations of it can be applied to all electronic circuits.

3. Three formulas for the solution of power dissipation in a resistor are given as equations (4), (5), and (6), and can be considered worthy of commitment to memory.

4. Kirchhoff made the observation that the sum of all the voltage drops occurring in a series circuit was always equal to the applied voltage. This fact led to the expression known as Kirchhoff's law, equation (7):

$$E_t = E1 + E2 + E3 \ . \ . \ . + E_n.$$

5. Exercise problems (diag 31).

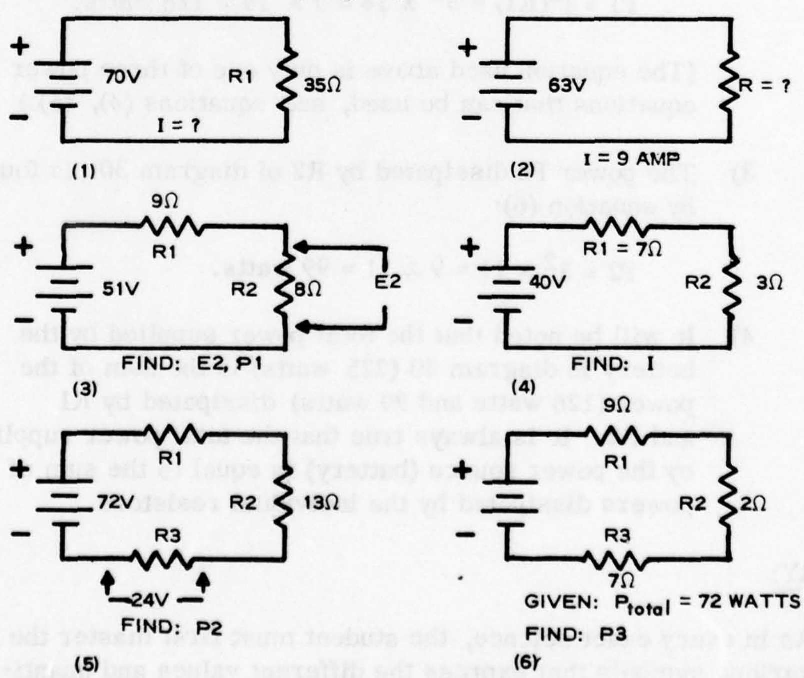


Diagram 31. Problems.

LESSON PLAN

PARALLEL DC CIRCUITS

OBJECTIVE:

To explain:

1. The essential differences between series and parallel circuits,
2. How to find the equivalent resistance of any number of equal resistors in parallel,
3. How to find the equivalent resistance of two unlike resistors in parallel,
4. How to find the equivalent resistance of any number of resistors in parallel,
5. The application of Kirchhoff's current law to parallel circuits, and
6. How to apply power equations to parallel circuits.

INTRODUCTION:

A parallel circuit is a circuit that provides two or more paths for current to flow between two points in a circuit. Diagram 32 illustrates a parallel circuit.

The arrows in diagram 32 indicate the three current paths between points X and Y. Each path is called a branch. Several methods of drawing a parallel circuit are shown in diagram 33.

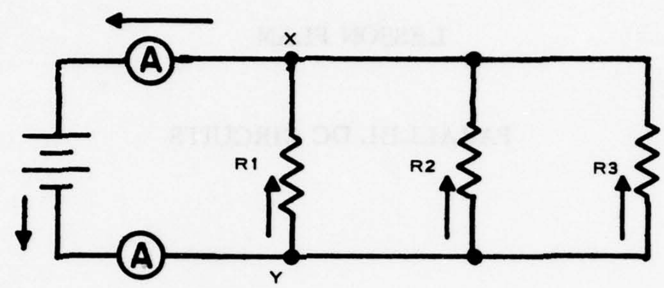


Diagram 32. Parallel circuit.

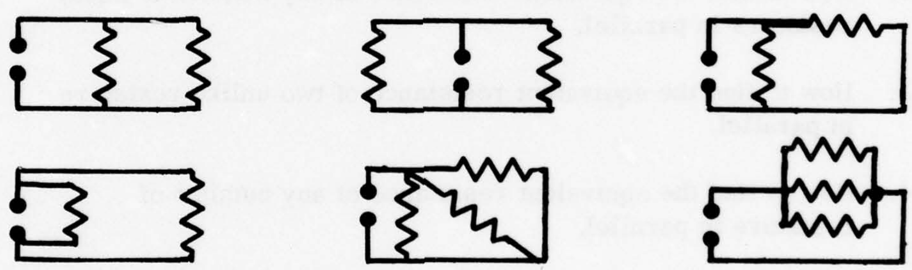


Diagram 33. Methods of drawing parallel circuits.

PRESENTATION:

1. Diagram 34 shows a 12v battery connected to an unknown circuit in a box. The ammeter shows that the battery is supplying three amperes to the circuit. By Ohm's law the circuit must have a resistance of four ohms.

2. The unknown circuit in the box of diagram 34 may be a single four-ohm resistor, as shown in diagram 35(1), but not necessarily; the combinations shown in diagram 35(2) and 35(3) also have a resistance of four ohms. In diagram 35(1) the resistor is actually a four-ohm resistor, but in 35(2) the four-ohm resistance is the equivalent resistance of the parallel combination of 6 ohms and 12 ohms. In 35(3) the resistance of 4 ohms is the equivalent resistance of 8 ohms, 9 ohms,

and 72 ohms, all connected in parallel. As far as the 12v battery is concerned, there is no distinction between the three circuits; they are all four-ohm circuits.

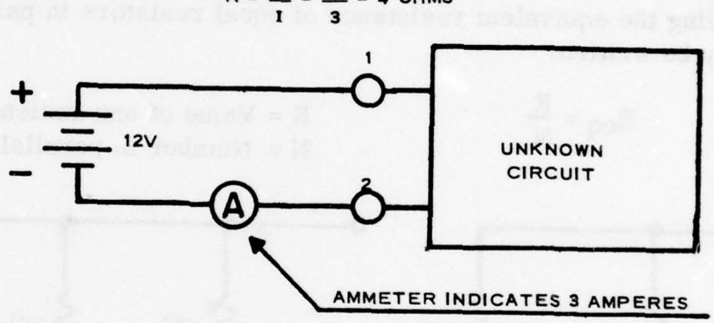


Diagram 34. Battery and unknown circuit.

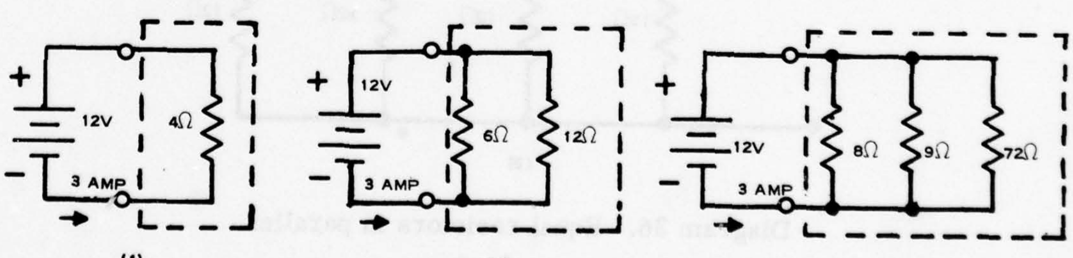


Diagram 35. Four-ohm circuits.

3. The equivalent resistance of two or more resistors of equal value connected in parallel is equal to the value of one resistance divided by the number of resistances in parallel. As an example, the equivalent resistance of the circuit in diagram 36(1) is 12 (the value of one) divided by 2 (the number in parallel) which gives a result of 6 ohms. The equivalent resistances of the circuits in diagram 36(2) and 36(3) are four ohms and three ohms, respectively. The equation for finding the equivalent resistance of equal resistors in parallel may be written:

$$R_{eq} = \frac{R}{N} \qquad \begin{array}{l} R = \text{Value of one resistor.} \\ N = \text{Number in parallel.} \end{array} \tag{8}$$

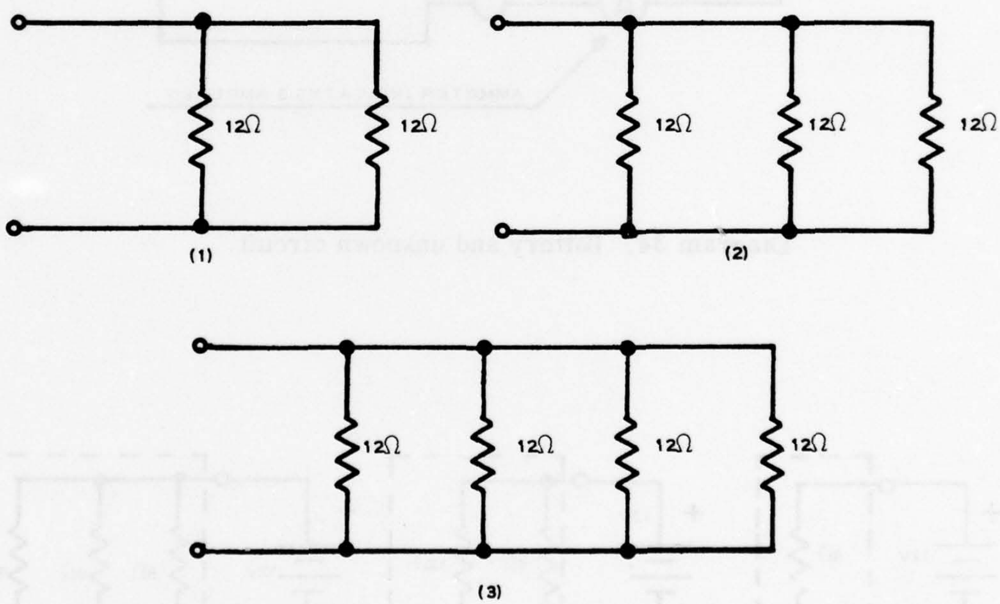


Diagram 36. Equal resistors in parallel.

4. The equivalent resistance of two unequal resistors in parallel is equal to their product divided by their sum. The equation may be written as:

$$R_{eq} = \frac{R1\ R2}{R1 + R2} \qquad \text{R1 and R2 are the two unequal resistors.} \tag{9}$$

Diagram 37 shows four circuits whose equivalent resistance should be calculated.

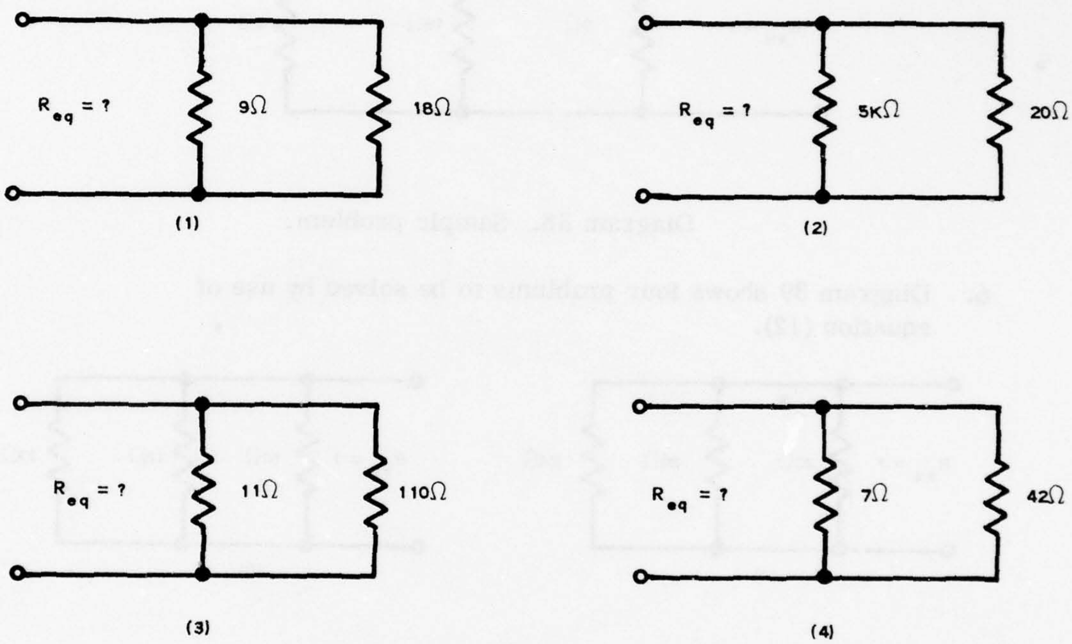


Diagram 37. Parallel circuit problems.

5. The equivalent resistance of any number of resistances connected in parallel is equal to the reciprocal of the sum of the reciprocals of the resistances in the individual branches.

$$R_{eq} = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \cdot \cdot \frac{1}{R_n}}. \qquad (10)$$

a. Diagram 38 shows a parallel circuit consisting of three resistors: 9 ohms, 18 ohms, and 3 ohms. The equivalent resistance may be found by using equation (10):

$$R_{eq} = \frac{1}{\frac{1}{9} + \frac{1}{18} + \frac{1}{3}} = \frac{1}{\frac{2}{18} + \frac{1}{18} + \frac{6}{18}} = \frac{1}{\frac{9}{18}} = \frac{18}{9} = 2 \text{ ohms}.$$

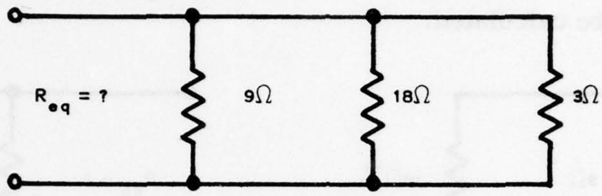


Diagram 38. Sample problem.

6. Diagram 39 shows four problems to be solved by use of equation (12).

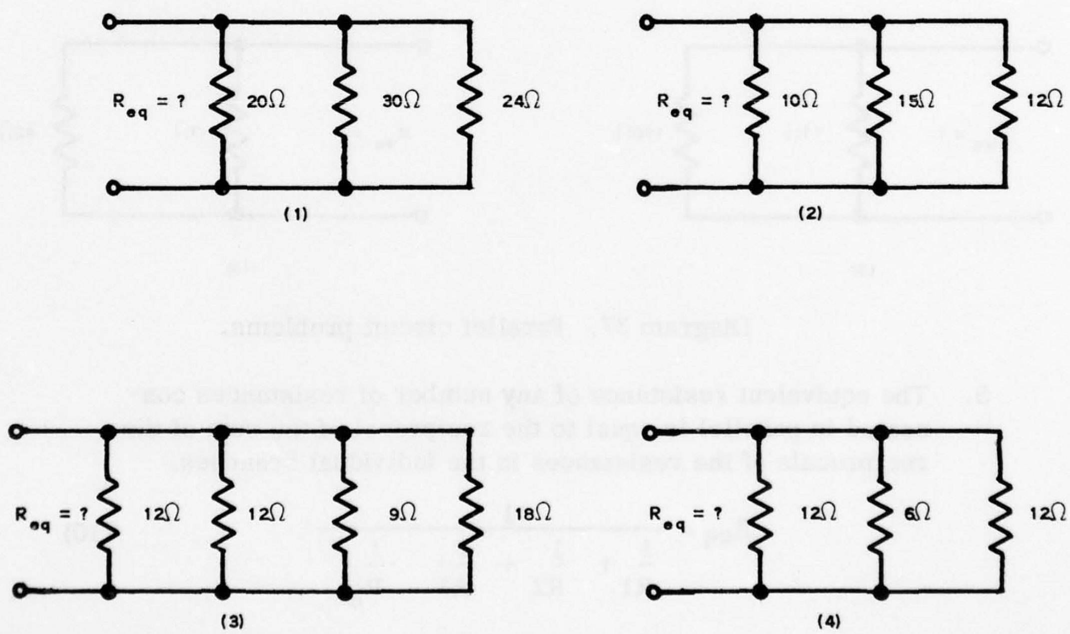


Diagram 39. Parallel circuit exercises.

7. The voltage across all branches of a parallel circuit is the same.
   a. Diagram 40 is the schematic diagram of a circuit in which the negative terminal (side) of a six-volt battery is connected to point X, and the positive terminal to point Y, and resistors R1, R2, and R3 are connected in parallel between points X and Y.

b. The voltage between junctions X and Y is the voltage applied to each resistor.

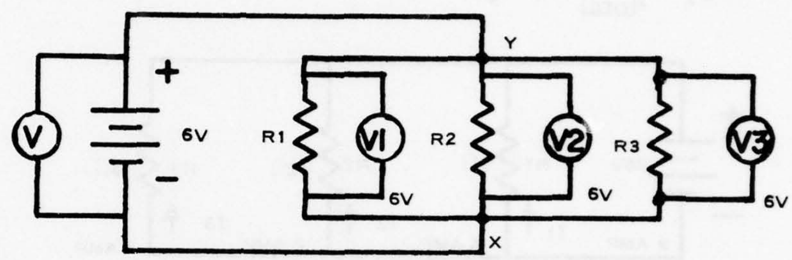


Diagram 40. Voltage in a parallel circuit.

Thus, voltmeters V1, V2, and V3 indicate the same voltage as the voltmeter across the battery. This illustrates a rule for voltage in parallel circuit.

c. In a parallel circuit, the same voltage is applied to each branch. The rule may be expressed mathematically as follows:

$$E = E1 = E2 = E3 \ldots\ldots\ldots = E_n. \qquad (11)$$

8. The equivalent resistance of a parallel circuit is always equal to the applied voltage (battery voltage) divided by the total current (battery current), as explained in paragraph 1. Therefore, an alternate method of determining the equivalent resistance of a parallel circuit may be used. The individual branch currents are calculated by Ohm's law, and <u>added</u> to find the total current. When the applied voltage is divided by the total current, the equivalent resistance is the result. An example of the above solution is seen in diagram 41 and is explained below.

a. $I1 = \frac{E}{R1} = \frac{36}{9} = 4$ amperes.

b. $I2 = \frac{E}{R2} = \frac{36}{12} = 3$ amperes.

c. $I3 = \frac{E}{R3} = \frac{36}{18} = 2$ amperes.

d. $I_{total} = I1 + I2 + I3 = 4 + 3 + 2 = 9$ amperes.

e. $R_{eq} = \dfrac{E}{I_{total}} = \dfrac{36}{9} = 4$ ohms.

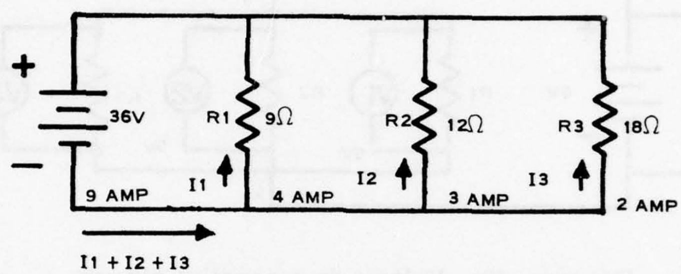


Diagram 41. Parallel branch currents.

9. Three simple rules for parallel dc circuits are summarized as follows:

   a. In a parallel circuit, the voltage across each branch is the same,

   b. In a parallel circuit, the total current is equal to the sum of the currents in the individual branches, and

   c. In a parallel circuit, the equivalent resistance is equal to the applied voltage divided by the total current, and is always less than the smallest resistance in the circuit.

10. Kirchhoff's current law states that the total amount of current flowing to a junction in an electrical circuit is equal to the amount of current flowing away from the junction. The circuit of diagram 42 illustrates the usefulness of Kirchhoff's current law.

    a. The ammeter in diagram 42 shows that current from the battery is flowing at the rate of 6 amperes toward the junction X.

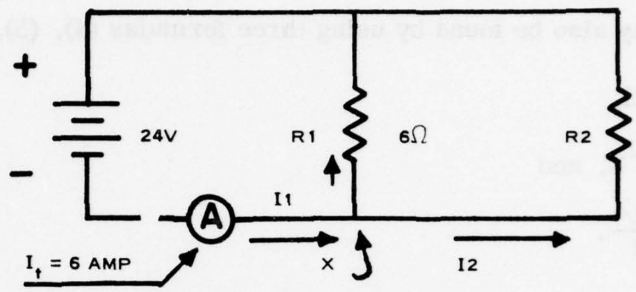


Diagram 42. Application of Kirchhoff's current law.

b. Using Ohm's law equation (1):

$$I_{R1} = \frac{E_{R1}}{R1}$$

$$I_{R2} = \frac{E_{R2}}{R2}$$

c. Using Kirchhoff's current law:

$$I_t = I_{R1} + I_{R2} + I_{R3} \cdot \cdot \cdot + I_{R_n} \qquad (12)$$

6 amperes = 4 amperes + 2 amperes.

d. Using Ohm's law to check:

$$I_t = \frac{E}{R_t}; \; R_t = \frac{1}{\frac{1}{6} + \frac{1}{12}} = \frac{12}{3} = 4\,\Omega \; .$$

$$I_t = \frac{24}{4} = 6 \text{ amperes.}$$

11. The power in a parallel circuit is similar to that in a series circuit. The total power is equal to the sum of power consumed by the individual branches.

$$P_t = P1 + P2 + P3 \qquad (13)$$

Power may also be found by using three formulas (4), (5), and (6):

a. $P = EI$,

b. $P = I^2R$, and

c. $P = \frac{E^2}{R}$.

12. The calculation of power in a parallel circuit is illustrated in the following example: In diagram 43, what is the power consumed by each resistor? What is the total power dissipated in the circuit?

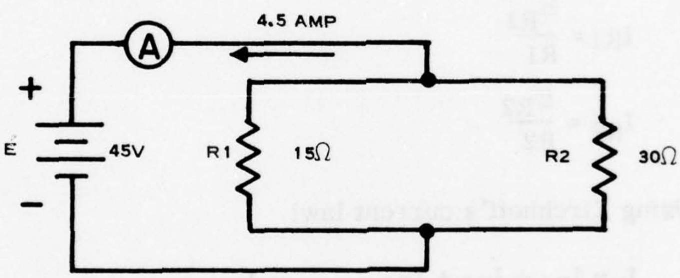


Diagram 43. Circuit for examples on power.

a. Solution.

1) Known quantities: | Desired quantities:

$E = 45$ volts, | P1,

$I = 4.5$ amperes, | P2, and

$R1 = 15$ ohms, and | P_{total}.

$R2 = 30$ ohms.

2) In the parallel circuit,

$E = E1 = E2 = 45$ volts,

$$P1 = \frac{E1^2}{R1} = \frac{(45)^2}{15} = \frac{(45)(3)}{1} = 135 \text{ watts, and}$$

$$P2 = \frac{E2^2}{R2} = \frac{(45)^2}{30} = \frac{(45)(3)(15)}{(2)(15)} = \frac{(45)(3)}{2} = \frac{135}{2} = 67.5 \text{ watts.}$$

3) Total power in the parallel circuit:

$P_t = P1 + P2$, therefore

$P_t = 135 + 67.5 = 202.5$ watts.

4) Check:

$P = EI$,

$P = 45$ volts x 4.5 amperes, and

$P = 202.5$ watts.

13. The exercise problems in diagram 44 utilize all equations and rules given in this lesson.

SUMMARY:

1. A parallel circuit is a circuit that offers two or more paths to the flow of electric current between any two points where a voltage exists.

2. The equivalent resistance of a parallel circuit is the effective resistance of all the paths that make up the parallel circuit and is always less than the path of least resistance. The solution of R_{eq} can be found using formulas (11) and (12).

3. Kirchhoff observed that the current flowing away from a junction, regardless of the number of paths, was always exactly equal to the current entering that junction:

$$I_t = I_{R1} + I_{R2} + I_{R3} \; . \; . \; . \; I_{R_n} \qquad (12)$$

INSTRUCTOR'S NOTE: Have someone use Kirchhoff's current law to explain why a fuse blows whenever too many appliances are plugged into a convenience outlet.

4. Ohm's law and Kirchhoff's current and voltage laws can be used in checking the accuracy of the solution of the relationships involved in any electronic circuit.

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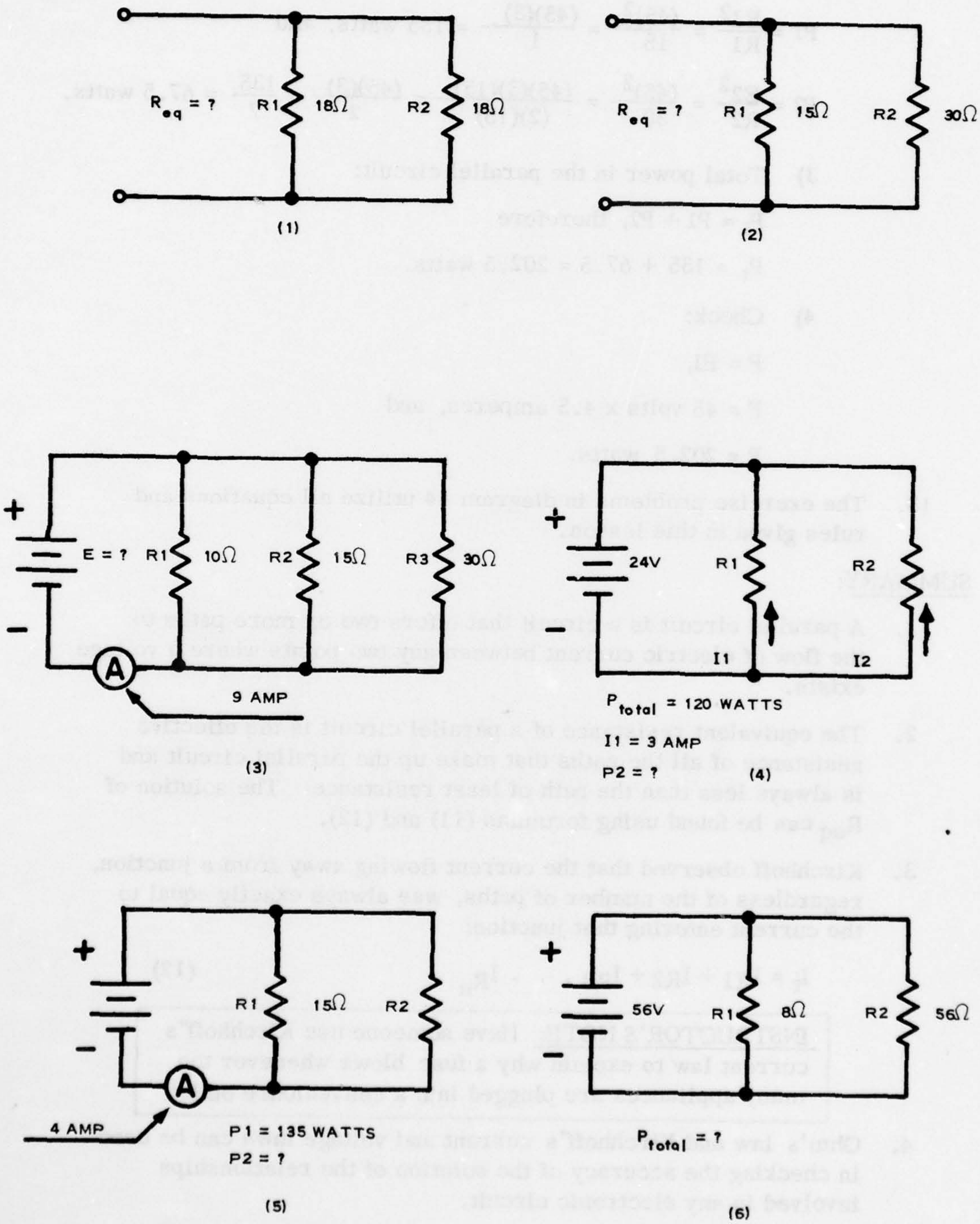

Diagram 44. Exercise problems.

LESSON PLAN

SERIES-PARALLEL DC CIRCUITS

OBJECTIVE:

To illustrate and explain:

1. A few series-parallel circuit combinations,

2. The method of simplifying series-parallel combinations of resistors into one equivalent resistance, and

3. How both Kirchhoff's voltage law and Kirchhoff's current law can be utilized in finding unknown values in complex resistor networks.

INTRODUCTION:

1. Most complex resistor networks may be simplified by applying the rules and equations presented in the lessons on series circuits and parallel circuits.

2. The solution of most resistor networks will be easily accomplished if the following rules, presented in previous lessons, are applied.

   a. The total resistance of a series circuit is equal to the sum of the individual resistances in series.

   b. The sum of the voltage drops in a series circuit is equal to the applied voltage.

   c. In a series circuit, the current is the same everywhere in the circuit.

   d. The total power supplied to any resistive circuit is equal to the sum of the powers dissipated in the individual resistors.

e. The voltage drop across resistors in parallel is the same.

f. The total current flowing toward any junction in a circuit is equal to the total current flowing away from that junction.

g. Four facts may be known about any resistor: resistance in ohms, voltage drop, current, and power dissipated. When any two facts are known, the other two may be calculated.

PRESENTATION:

1. A series-parallel circuit is a combination of series and parallel circuits. Various series-parallel circuits are shown in diagram 45.

2. In diagram 46, resistors R2 and R3 are in parallel. This parallel group is in series with resistor R1 and the battery. In a parallel circuit, the same voltage is applied to each branch. Thus, the voltage across R2 is equal to the voltage across R3. From Kirchhoff's voltage law, the voltage across R1 plus the voltage across the parallel group is equal to the applied voltage. The voltage relationship in a series-parallel circuit may be stated mathematically as follows:

$$E_t = E1 + E2,3 \qquad (14)$$

where E2, 3 = voltage across the parallel group R2 and R3.

3. The current flow in a series-parallel circuit has more than one path. In diagram 47, the current I from the negative terminal of the battery goes through R1 to point X. At point X, the current divides, part I2 going through R2 and the remainder, I3, going through R3. At point Y, these two circuits reunite (I2 + I3 = I) and flow to the positive terminal of the battery and through the battery to the negative terminal. It should be noted that Kirchhoff's current law is applicable to the series-parallel circuit.

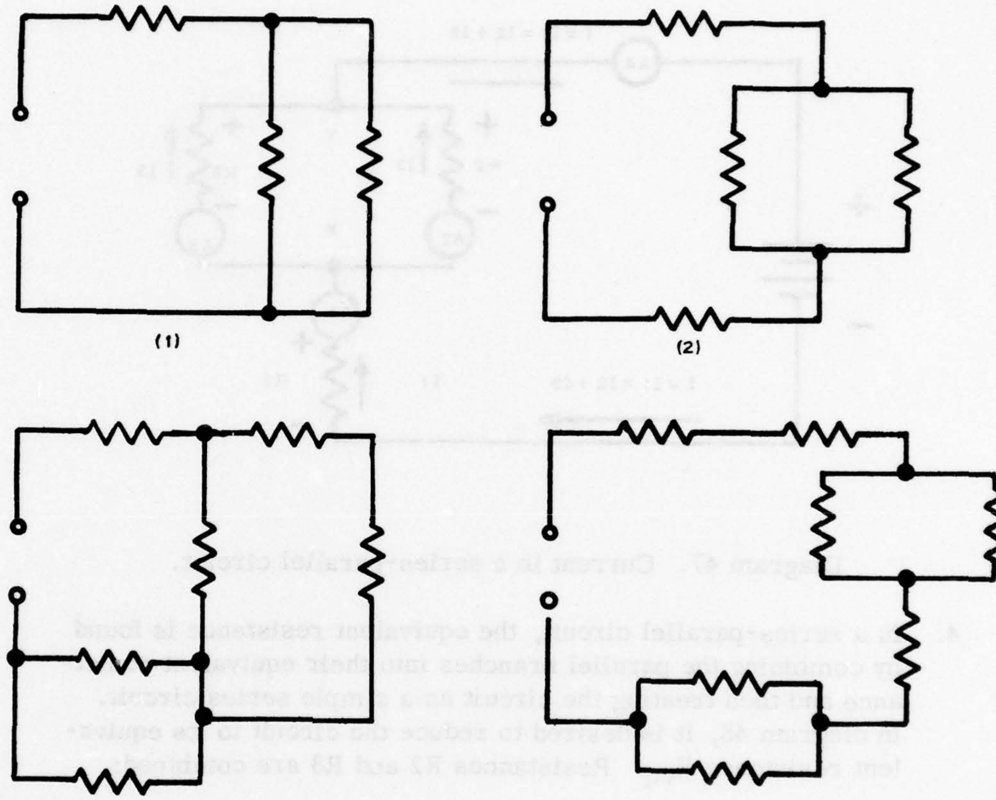

Diagram 45. Types of series-parallel circuits.

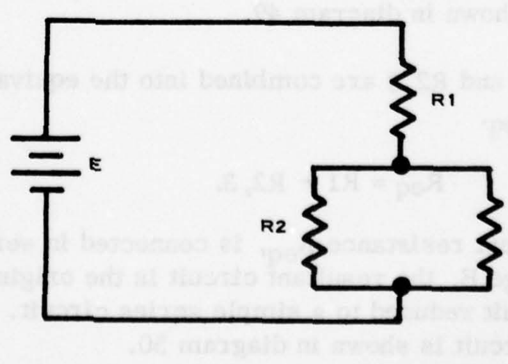

Diagram 46. Voltage drops in a series-parallel circuit.

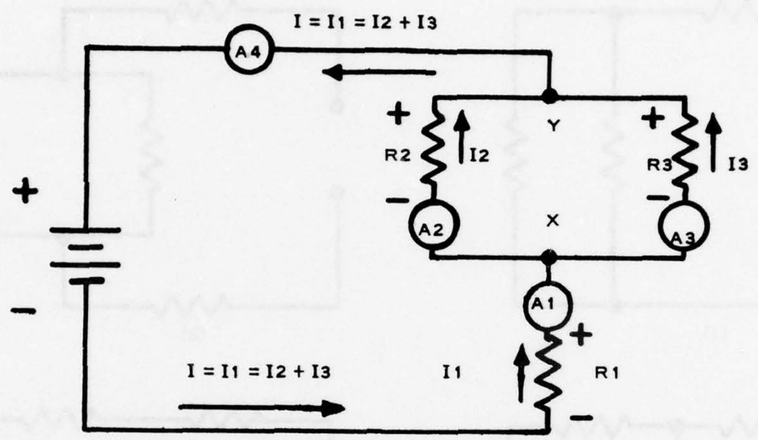

Diagram 47. Current in a series-parallel circuit.

4. In a series-parallel circuit, the equivalent resistance is found by combining the parallel branches into their equivalent resistance and then treating the circuit as a simple series circuit. In diagram 48, it is desired to reduce the circuit to its equivalent resistance R_{eq}. Resistances R2 and R3 are combined:

$$R2, 3 = \frac{R2\ R3}{R2 + R3}. \tag{15}$$

The value of R2, 3 (equivalent of R2 and R3) is placed in series with R1, as shown in diagram 49.

Resistors R1 and R2, 3 are combined into the equivalent resistance R_{eq}.

$$R_{eq} = R1 + R2, 3.$$

If the equivalent resistance R_{eq}, is connected in series with the applied voltage E, the resultant circuit is the original series-parallel circuit reduced to a simple series circuit. The simple equivalent circuit is shown in diagram 50.

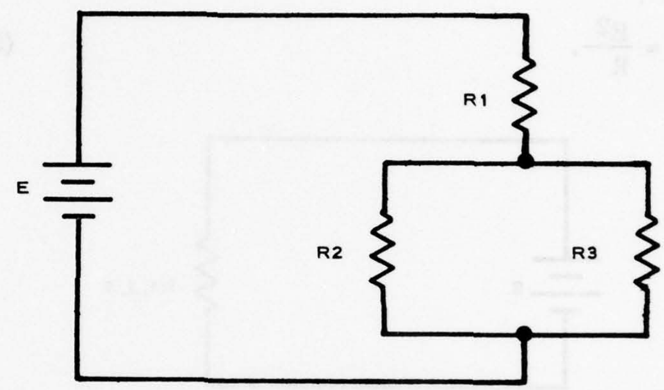

Diagram 48. Series-parallel circuit.

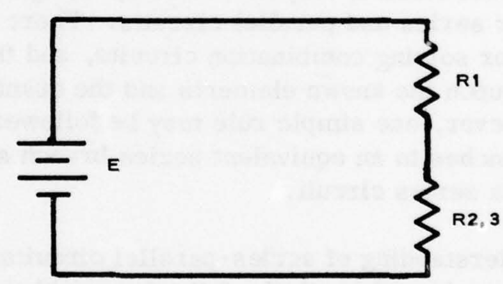

Diagram 49. Equivalent series circuit.

> INSTRUCTOR'S NOTE: R_{eq} can be replaced by R_t whenever R_{eq} is used to denote the equivalent resistance of the entire circuit.

5. The power formulas that are used in series and parallel circuits are equally applicable to series-parallel circuits. The formulas are:

$$P = P1 + P2 + P3 \ . \ . \ . + P_n, \qquad (13)$$

$$P = EI, \qquad (4)$$

$$P = I^2R, \text{ and} \qquad (6)$$

$$P = \frac{E^2}{R}. \qquad (5)$$

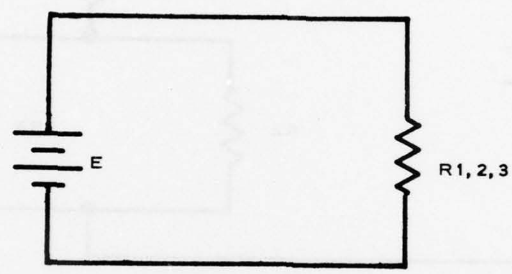

Diagram 50. Simple series circuit.

6. Series-parallel circuits may be solved by using Ohm's law and the rules for series and parallel circuits. There is no definite procedure for solving combination circuits, and the solution will depend upon the known elements and the quantities to be found. However, one simple rule may be followed: Reduce the parallel branches to an equivalent series branch and solve the problem as a series circuit.

7. A better understanding of series-parallel circuits may be obtained by working through the following problems.

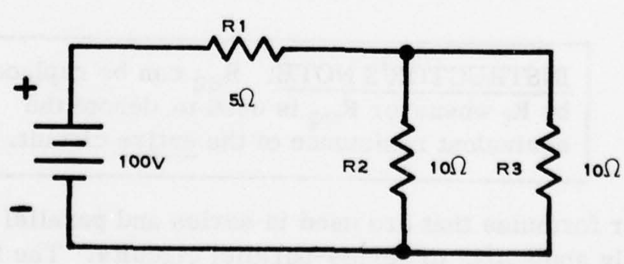

Diagram 51. Circuit for problem A.

a. Problem A.

Using the circuit in diagram 51, find the total resistance, the current through each resistor, the voltage drop across each resistor, the power dissipated by each resistor, and the total power.

1) Reduce the parallel combination of R2 and R3 into an equivalent series resistance. Since R2 and R3 are in parallel and are of the same value, their equivalent resistance by equation (8) is equal to:

$$R_{eq} = R2, 3 = \frac{R}{N} = \frac{10}{2} = 5 \text{ ohms.}$$

2) There now remains an equivalent series circuit with two resistors of five ohms each in series as shown in diagram 52.

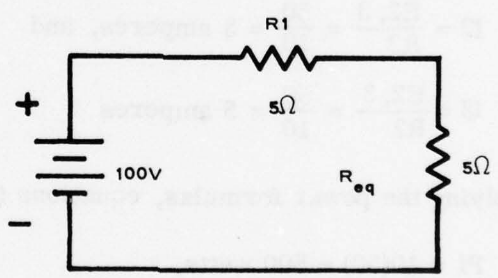

Diagram 52. Equivalent circuit for problem A.

The total resistance in the equivalent series circuit may be found by adding the two resistances:

$$R_t = R1 + R2, 3$$

$$= 5 + 5 = 10 \text{ ohms.}$$

3) To find the line current I_t, Ohm's law may be applied to the entire circuit, equation (1):

$$I_t = \frac{E}{R_t}$$

$$= \frac{100v}{10} = 10 \text{ amperes.}$$

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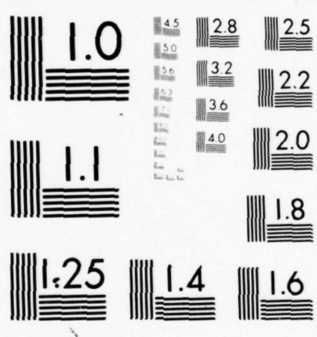

MICROCOPY RESOLUTION TEST CHART

The total line current must flow through R1. Applying Ohm's law, equation (3), to R1:

$$E1 = I(R1)$$

$$= 10 \times 5 = 50 \text{ volts.}$$

If 50 volts of the applied voltage are dropped across R1, the remaining voltage must be dropped across the parallel combination of R2 and R3 or its equivalent resistance. R2, 3 (diag 51).

$$E = E1 + E2,3 \text{ by equation (14).}$$

$$E2,3 = E - E1 = 100 - 50 = 50 \text{ volts.}$$

Applying Ohm's law to R2 and R3,

$$I2 = \frac{E2,3}{R2} = \frac{50}{10} = 5 \text{ amperes, and}$$

$$I3 = \frac{E2,3}{R2} = \frac{50}{10} = 5 \text{ amperes}$$

4) Applying the power formulas, equations (4) and (13):

$$P1 = 10(50) = 500 \text{ watts,}$$

$$P2 = 5(50) = 250 \text{ watts,}$$

$$P3 = 5(50) = 250 \text{ watts, and}$$

$$P = P1 + P2 + P3 = 500 + 250 + 250$$

$$= 1,000 \text{ watts.}$$

b. Problem B.

Using the circuit in diagram 53, find the total resistance, the current through each resistor, and the voltage across each resistor.

1) The equivalent resistance of the entire circuit may be found by reducing the circuit to a simple series circuit. Resistors R6 and R7 may be added as in a series circuit:

$$R6,7 = R6 + R7 = 20 + 16 = 36 \text{ ohms.}$$

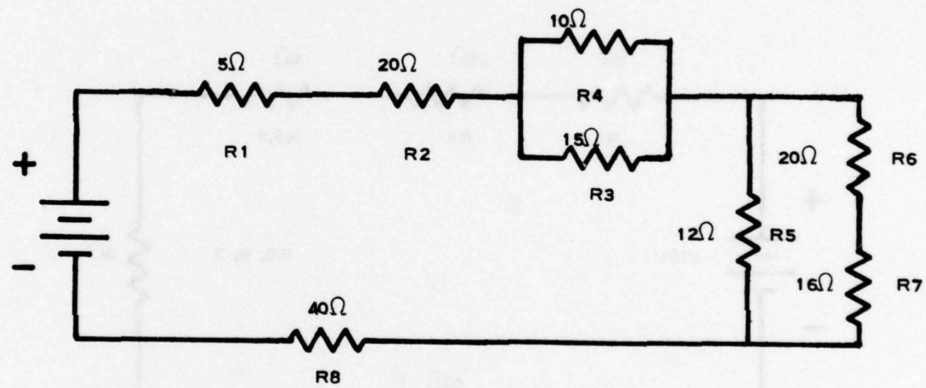

Diagram 53. Circuit for problem B.

2) R5 and R6, 7 are then combined as in a parallel circuit to give their equivalent resistance. Since they are parallel branches of unequal resistance, by equation (9):

$$R5\ R6,7 = \frac{R5\ R6,7}{R5 + R6,7}$$

$$= \frac{(12)(36)}{12 + 36} = \frac{432}{48} = 9 \text{ ohms.}$$

3) Resistors R3 and R4 may be combined by equation (9) to find their equivalent resistance:

$$R3,4 = \frac{(R3)(R4)}{R3 + R4}$$

$$= \frac{(15)(10)}{25} = \frac{150}{25} = 6 \text{ ohms.}$$

4) There now remains a series circuit consisting of R1, R2, R3, 4, R5, 6, 7, and R8, as shown in diagram 54. To find the total resistance of the circuit, all resistances are added:

$$R_t = R1 + R2 + R3,4 + R5,6,7 + R8$$

$$= 5 + 20 + 6 + 9 + 40 = 80 \text{ ohms.}$$

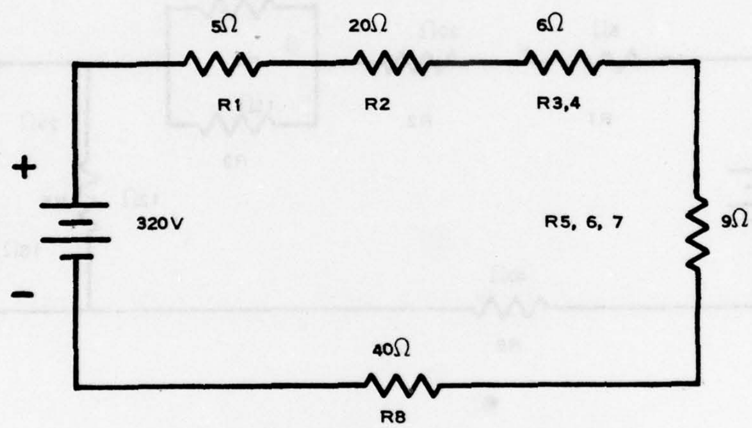

Diagram 54. Equivalent circuit for problem B.

5) To find the line current, Ohm's law equation (1) may be applied to the entire circuit:

$$I = \frac{E}{R_t} = \frac{320}{80} = 4 \text{ amperes.}$$

6) Still treating the original circuit as the series circuit of diagram 54, the current is the same through each resistor and equivalent resistance. Ohm's law, equation (3), may be applied to each resistor and equivalent resistance to find the voltage drop.

$$E1 = 4 \times 5 = 20 \text{ volts.}$$

$$E2 = 4 \times 20 = 80 \text{ volts.}$$

$$E3,4 = 4 \times 6 = 24 \text{ volts.}$$

7) Since R3 and R4 are in parallel in the original circuit, the voltage across R3 is the same as that across R4. Therefore,

$$E3, 4 = E3 = E4 = 24 \text{ volts.}$$

$$E5, 6, 7 = IR5, 6, 7 = 4 \times 9 = 36 \text{ volts.}$$

8) Since R5 and R6, 7 are in parallel, the voltage across R5 is the same as that across R6, 7, and

$$E5, 6, 7 = E5 = E6, 7 = 36 \text{ volts.}$$

9) Since R6 and R7 are in series, the current through them by equation (1) is:

$$I6, 7 = \frac{E6, 7}{R6, 7}$$

$$= \frac{36}{36} = 1 \text{ ampere.}$$

10) Applying Ohm's law, equation (3):

$$E6 = (I6, 7)\, R6 = 1 \times 20 = 20 \text{ volts.}$$

$$E7 = (I6, 7)\, R7 = 1 \times 16 = 16 \text{ volts.}$$

$$E8 = I(R8) = 4 \times 40 = 160 \text{ volts.}$$

11) The voltage drop across each resistor has been determined and is summarized below.

E1 = 20 volts.	E5 = 36 volts.
E2 = 80 volts.	E6 = 20 volts.
E3 = 24 volts.	E7 = 16 volts.
E4 = 24 volts.	E8 = 160 volts.

12) The volue of each resistor has been given, and the voltage across each resistor has been determined. Ohm's law may be applied to each resistor to determine its current.

$$I1 = \frac{E1}{R1} = \frac{20}{5} = 4 \text{ amperes.}$$

$$I2 = \frac{E2}{R2} = \frac{80}{20} = 4 \text{ amperes.}$$

$$I3 = \frac{E3}{R3} = \frac{24}{15} = 1.6 \text{ amperes.}$$

$$I4 = \frac{E4}{R4} = \frac{24}{10} = 2.4 \text{ amperes.}$$

$$I5 = \frac{E5}{R5} = \frac{36}{12} = 3 \text{ amperes.}$$

$$I6 = \frac{E6}{R6} = \frac{20}{20} = 1 \text{ ampere.}$$

$$I7 = \frac{E7}{R7} = \frac{16}{16} = 1 \text{ ampere.}$$

$$I8 = \frac{E8}{R8} = \frac{160}{40} = 4 \text{ amperes.}$$

13) Check: It can be seen from the circuit of diagram 53 that the line current flows through R1, R2, and R8. This agrees with the above calculations for I1, I2, and I8. The sum of the currents through R3 and R4 should equal line current.

$$I = I3 + I4 = 1.6 + 2.4 = 4 \text{ amperes.}$$

Since R6 and R7 are in series, the same current flows through R6 and R7. Thus:

$$I6,7 = I6 = I7 = 1 \text{ ampere.}$$

The sum of the currents through the parallel branches of R5 and R6, 7 should equal the line current.

I = I5 + I6, 7 = 3 + 1 = 4 amperes.

INSTRUCTOR'S NOTE: Devise other circuits similar to the foregoing problems and put them on the blackboard for the students to solve.

SUMMARY:

1. Simplification is the key to the solution of complex resistor networks. If the student understands the rules set forth in the introduction to this chapter and can apply the correct formulas in an intelligent manner, he will find himself solving problems which, at first inspection, appeared extremely formidable and perhaps more than equal to his ability.

2. It should be noticed that solutions of all complex resistor networks are preceded by the reduction of all the branches of the circuit into their equivalent resistances, and then treating the circuit as a series circuit in order to facilitate the computation of the total current. Once total current is known, it becomes a simple operation to employ Ohm's law to the solution of all the circuit elements, be they single resistors or multiple resistors in parallel networks.

LESSON PLAN

INTRODUCTION TO ALTERNATING CURRENTS

OBJECTIVE:

To explain and to demonstrate by means of diagrams:

1. The differences and similarities of direct currents and alternating currents; and

2. Definitions of the terms cycle, frequency, period, alternation, polarity, electrical degree, phase, peak voltage and peak current, and root-mean-square values of voltage and current.

INTRODUCTION:

1. Alternating voltages and currents are of prime importance in the study of electronics because practically all signals and control voltages involve changes of voltage amplitude. Any continual change of voltage amplitude may be considered as alternating in character.

2. An alternating current is one that flows in a conductor first in one direction and then in the opposite direction.

PRESENTATION:

1. Diagram 55 is a graphical representation of an alternating voltage showing how an ac voltage varies with time. The voltage shown is similar to that used in homes for lighting or operating small ac motors. The frequency of the usual ac used in homes is 60 cycles per second (or 60 cps), and an ac voltmeter would show the voltage to be 115v.

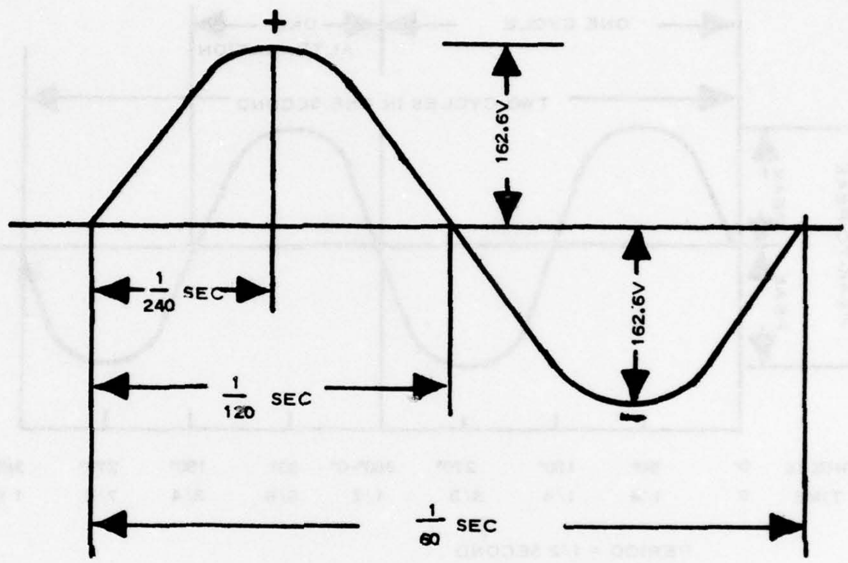

Diagram 55. One cycle of 60-cps ac voltage.

The voltage at any instant, however, is not a constant value. The diagram shows that the voltage rises from 0 to a peak of 162.6v in the positive direction, falls to 0, rises to a peak of 162.6v in the negative direction, then falls to 0 again. The series of changes described completes one cycle, and this cycle is repeated 60 times per second.

2. It will be noted in diagram 55 that one cycle is completed in 1/60 second (since the frequency of the ac voltage is 60 cycles per second), and smaller parts of the cycle are designated as occurring in smaller periods of time.

3. The indicated times (in seconds) for small parts of the cycle (diag 55) are correct for a frequency of 60 cycles per second but would not be correct for other frequencies. Since indicating periods of time in seconds becomes too cumbersome for practical work, degrees are used as shown in diagram 56.

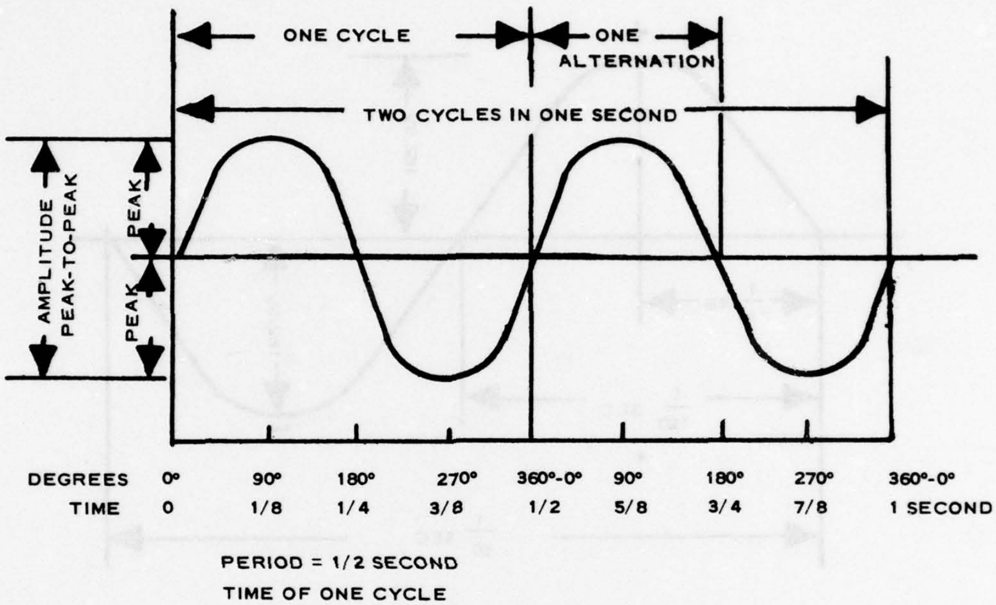

Diagram 56. Variations of an ac voltage having a frequency of two cps.

4. Definitions of AC Values.

a. When the voltage goes through one complete set of changes and is ready to start through the same set of changes again, one cycle has been completed. In diagram 56 the voltage has completed one cycle at the end of 1/2 second.

b. Frequency is the number of cycles completed in one second. From diagram 56 it can be seen that two cycles are completed in one second; therefore, the frequency is two cycles per second.

c. The period of an alternating voltage is the time in seconds to complete one cycle. In diagram 56 one cycle is completed in 1/2 second, therefore the period is 1/2 second. The period in seconds for any frequency is equal to the reciprocal of the frequency in cycles per second.

$$\text{Period in seconds} = \frac{1}{\text{Frequency in cps}} \qquad (16)$$

d. An alternation can be defined as the change occurring as the voltage rises from zero to its maximum value in one direction and then returns to zero. There is no reversal of direction involved in one alternation. There are two positive and two negative alternations shown in diagram 56.

e. The polarity of an alternation changes as it passes zero: positive above zero and negative below zero.

f. The maximum or peak amplitude is the greatest amplitude of voltage, either positive or negative, that occurs during a cycle (diag 57).

g. The voltage waveform shown in diagram 57 is referred to as a sine wave because the voltage at any instant during the cycle is equal to the peak voltage multiplied by the sine of the angle (in electrical degrees).

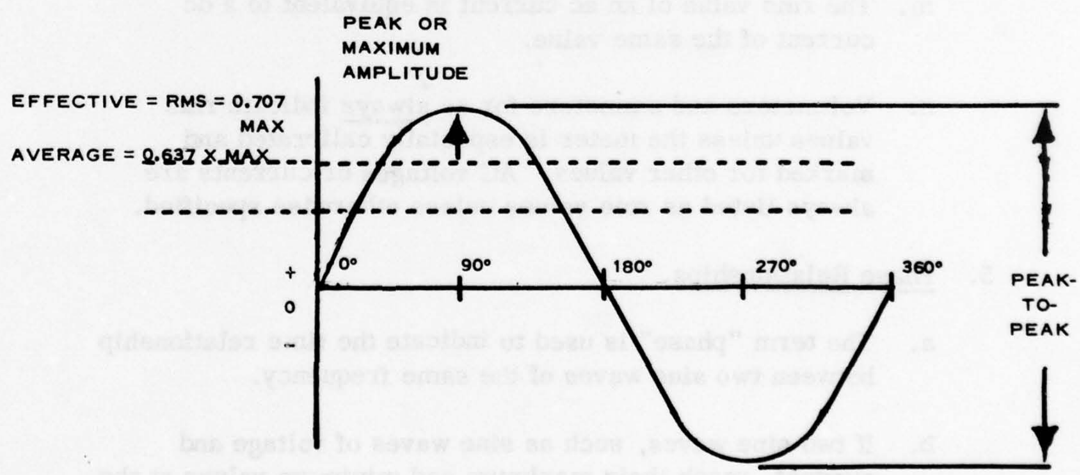

Diagram 57. Sine wave values and averages.

h. The peak-to-peak value of an ac voltage is the total difference in voltage between the maximum positive and maximum negative voltage occurring during one cycle (diag 57).

i. The root-mean-square (rms) voltage of a sine wave of voltage is equal to the square root of the average squares of all of the instantaneous values during one complete cycle. The rms voltage may be referred to as the effective value.

j. The rms voltage of a sine wave of voltage is equal to 70.7 percent of the peak voltage (diag 57).

$$E = 0.707 \times E_{max} \tag{17}$$

k. The rms voltage of a sine wave of voltage will do the same amount of work in a given time as a dc voltage of the same value.

l. The rms value of a sine wave of current is equal to 70.7 percent of the peak value of current.

$$I = 0.707 \times I_{max} \tag{18}$$

m. The rms value of an ac current is equivalent to a dc current of the same value.

n. Voltmeters and ammeters for ac always indicate rms values unless the meter is especially calibrated and marked for other values. AC voltages or currents are always listed as rms values unless otherwise specified.

5. Phase Relationships.

a. The term "phase" is used to indicate the time relationship between two sine waves of the same frequency.

b. If two sine waves, such as sine waves of voltage and current, reach their maximum and minimum values at the same instant (diag 58), they are in phase.

c. If two sine waves, such as sine waves of voltage and current, do not reach their maximum or minimum voltages at the same instant, they are "out of phase" (diag 59).

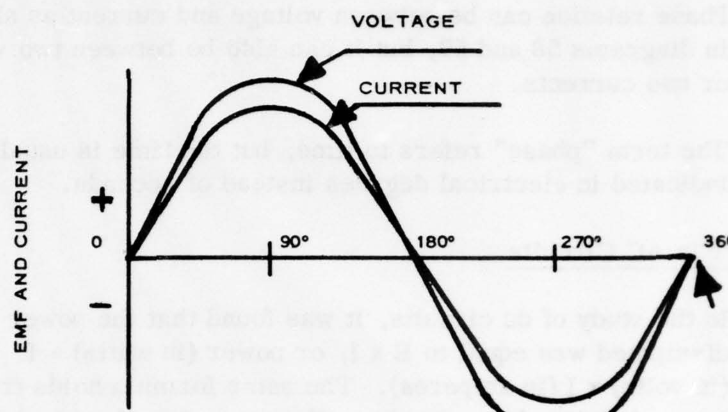

Diagram 58. Curves showing emf and current in phase.

d. In diagram 59 it can be seen that the voltage increases from 0° to 60° earlier than the time at which the current rises from zero. It might be said that the voltage in diagram 59 leads the current by 60°, but it would be just as proper to say that the current <u>lags</u> the voltage by 60°.

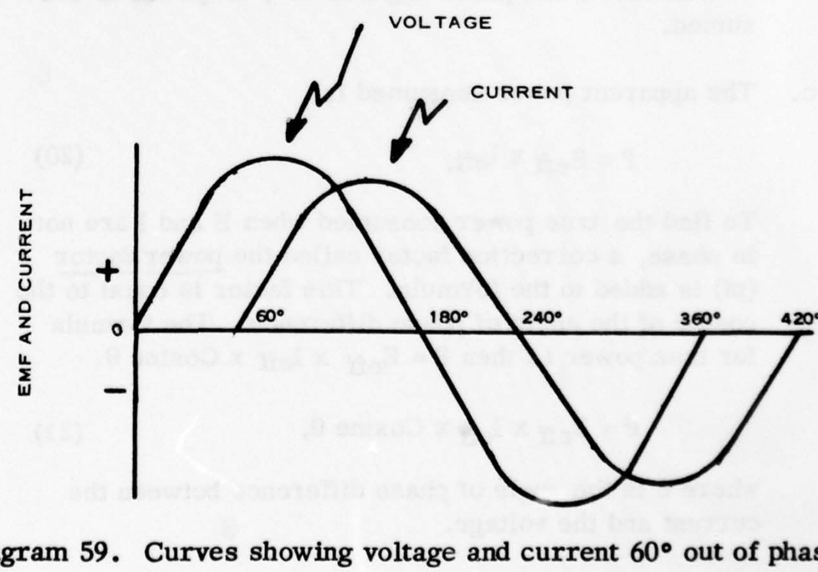

Diagram 59. Curves showing voltage and current 60° out of phase.

e. Phase relation can be between voltage and current as shown in diagrams 58 and 59, but it can also be between two voltages or two currents.

f. The term "phase" refers to time, but the time is usually indicated in electrical degrees instead of seconds.

6. Power in AC Circuits.

a. In the study of dc circuits, it was found that the power dissipated was equal to E x I, or power (in watts) = E (in volts) x I (in amperes). The same formula holds true in ac circuits, but only when effective values (rms) of E and I are used and the voltage and current are in phase. The voltage and current are always in phase in a pure resistance.

$$\text{Power} = E_{rms} \times I_{rms} \tag{19}$$

b. When the voltage and current are not in phase, they are not working together and less power is consumed. The larger the angle of phase difference, the less power is consumed. If the phase angle is 90°, no power is consumed.

c. The apparent power consumed is:

$$P = E_{eff} \times I_{eff}. \tag{20}$$

To find the true power consumed when E and I are not in phase, a correction factor called the power factor (pf) is added to the formula. This factor is equal to the cosine of the angle of phase difference. The formula for true power is then $P = E_{eff} \times I_{eff} \times \text{Cosine } \theta$.

$$P = E_{eff} \times I_{eff} \times \text{Cosine } \theta, \tag{21}$$

where θ is the angle of phase difference between the current and the voltage.

SUMMARY:

1. A cycle has been completed when an electrical waveform goes through a series of changes and is ready to repeat the series.

2. Alternations are the two parts of each cycle of alternating current or voltage. All values in an alternation are directly opposite to, or in a different direction from, all values in the other alternation.

3. Polarity is the condition of having opposite parts or directions. It denotes directions of current, voltage, and magnetic fields.

4. Sine wave is a quantity whose instantaneous magnitude is proportional to the sine of an angle which is constantly changing from 0° to 360°.

5. Electrical degree is one-360th of a cycle.

6. Period is the time required for one cycle.

7. Frequency is the number of cycles per second.

8. Amplitude is the maximum height of a sine wave above or below its reference level.

9. Instantaneous value is the height of the wave above or below the reference level at any given instant.

10. Phase is the time difference, in degrees, between one sine wave and a reference point or between two sine waves of the same frequency. One sine wave which occurs sooner than another is said to lead by so many degrees. The latter wave is said to lag the first one by the same number of degrees.

LESSON PLAN

INDUCTANCE

OBJECTIVE:

To explain and demonstrate by means of diagrams:

1. The definition of inductance,
2. The electrical properties of inductance,
3. The voltage and current relationships in a pure inductance, and
4. The method of calculating inductive reactance.

INTRODUCTION:

Inductance is one of the three basic properties found in every electronic circuit; the other two are capacitance and resistance. The effect of inductance can be noted every time the current changes in a circuit. Inductance is an important property of all conductors. The large power transformer with its iron core has a large amount of inductance, and a straight wire one inch long has a small amount of inductance. Inductors, both large and small, are used frequently in all types of electronic equipment. A thorough knowledge of the effects of inductance is necessary in order to understand even the simplest piece of electronic equipment.

PRESENTATION:

1. When an electric current is made to flow through a conductor, a magnetic field is built up around the conductor. The field takes the form of concentric circles around the conductor that are everywhere perpendicular to the axis of the conductor as shown in diagram 60.

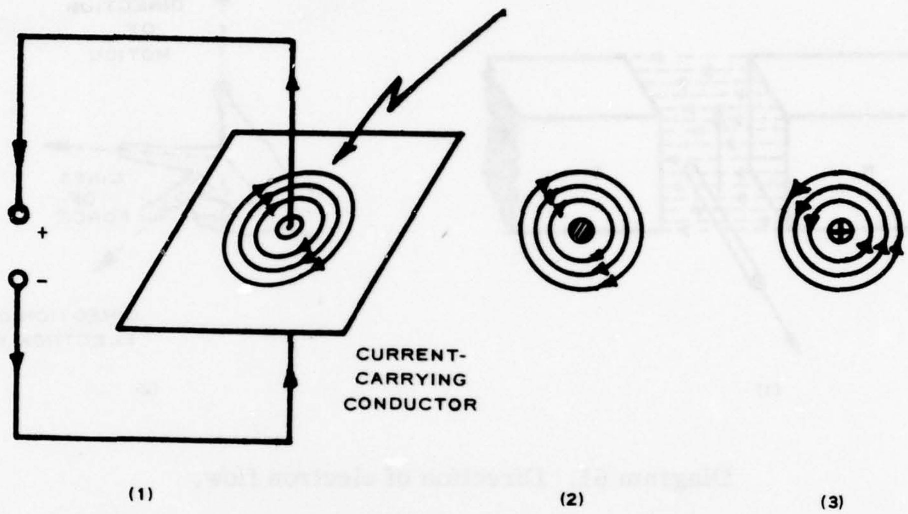

Diagram 60. Magnetic field around a current-carrying conductor.

2. It has been shown that a voltage can be induced in a conductor by moving it through a magnetic field. It has also been shown that the same voltage can be induced in the conductor by moving the magnetic field past the conductor. In diagram 61, a conductor is shown cutting through a magnetic field. The direction of the induced voltage is determined by the left hand rule as shown in diagram 61. If the conductor were made stationary and the magnets were moved downward past the conductor, a voltage would be induced in the same direction as before, since the relative motion of the conductor through the field has not changed. A moving magnetic field cutting through a conductor induces a voltage in that conductor.

3. When a current-carrying conductor is formed into a loop (diag 62), the magnetic lines of force are concentrated inside the loop. In other words, the magnetic lines of force about the conductor are all going in the same direction inside the loop. If the conductor is coiled so that a number of loops are formed, the magnetic lines of force from all of the loops are concentrated in the center of the coil.

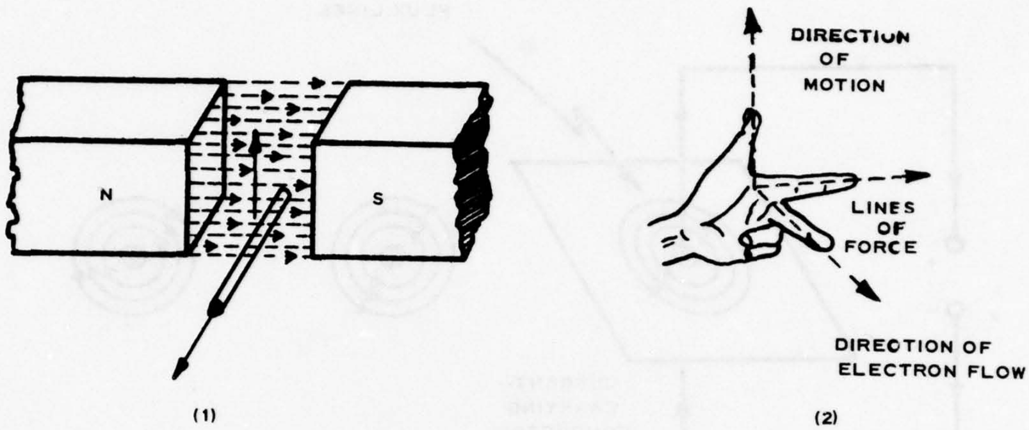

Diagram 61. Direction of electron flow.

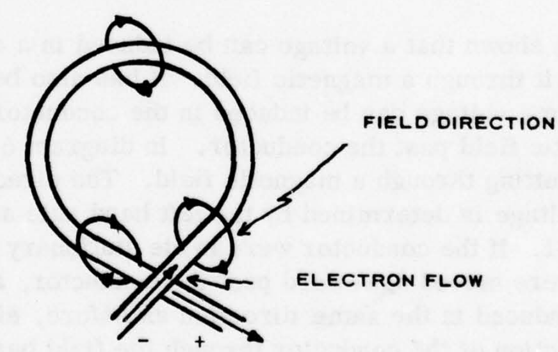

Diagram 62. Field about a loop-carrying current.

4. As the current increases in the conductors of the coil shown in diagram 63(1), the magnetic lines of force expand outward from each conductor. As they expand outward they cut through all of the other conductors of the coil and induce a voltage in them. When the current reaches a steady value, the magnetic field becomes stationary as shown in diagram 63(2), and no voltage is induced in the turns of the coil. As the current in the conductors begins to decrease, the magnetic field begins to collapse or move back into the individual conductor where it originated. As the field collapses, the lines of force from each

conductor cut through all of the other conductors and again induce a voltage in them of opposite polarity.

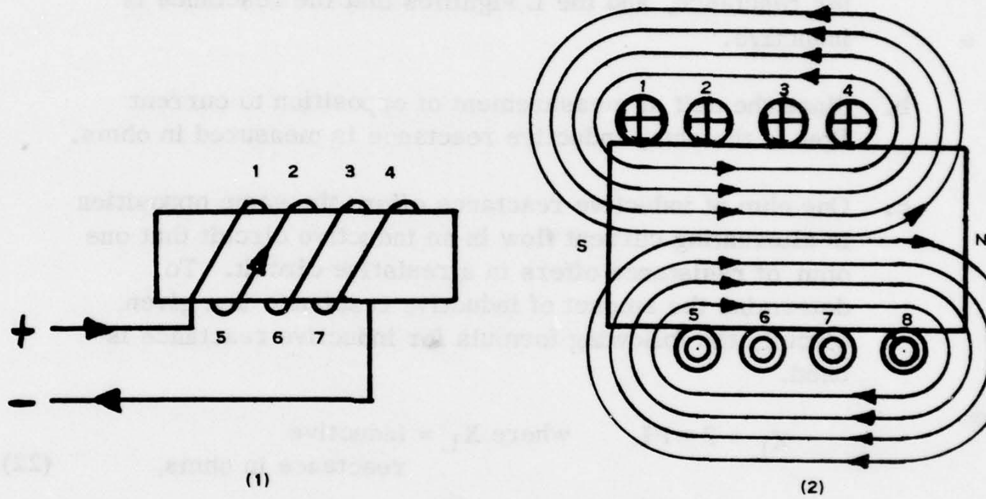

Diagram 63. Magnetic field caused by a current's flowing through a coil.

The voltage induced in an inductor is always in such a direction as to oppose a change in the current that induced the voltage.

5. Inductance may be defined as that property of a conductor which tends to oppose any change of current flow in that conductor.

a. The unit of inductance is the <u>henry.</u> A coil has an inductance of one henry when a change of current of one ampere per second will induce a voltage of one volt across the coil.

b. A device added to a circuit for the purpose of providing or increasing the inductance is called an inductor.

c. When an alternating voltage is applied to a pure inductance, the current lags the applied voltage by 90 electrical degrees.

6. The opposition of ac flow offered by an inductance is called inductive reactance.

   a. The symbol for inductive reactance is X_L. The X stands for reactance, and the L signifies that the reactance is inductive.

   b. Since the unit of measurement of opposition to current flow is the ohm, inductive reactance is measured in ohms.

   c. One ohm of inductive reactance offers the same opposition to alternating current flow in an inductive circuit that one ohm of resistance offers in a resistive circuit. To determine the amount of inductive reactance in a given circuit, the following formula for inductive reactance is used.

$$X_L = 2\pi FL \qquad (22)$$

where X_L = inductive reactance in ohms,

π = 3.1416,

F = the frequency in cycles per second, and

L = the inductance in henries.

   From the formula we see that if either the frequency or the inductance is increased, X_L will increase.

   d. The current that flows through an inductor is equal to the applied voltage divided by the inductive reactance.

   e. The net power dissipated by a pure inductance is zero.

SUMMARY:

1. Relative motion between a conductor and lines of force will induce a voltage in that conductor.

2. When an alternating current increases and decreases in a conductor, the expanding and contracting magnetic field about the conductor cuts through the conductor and induces an alternating emf in the conductor.

3. Inductance is that property of a circuit which tends to oppose any change of current in the circuit.

4. The unit of induc'ance is the henry.

5. An inductor is a device added to a circuit to increase the inductance of the circuit.

6. The current in an inductive circuit lags the voltage across the inductor by 90°.

7. The current flow through a pure inductance is equal to the applied voltage divided by the inductive reactance.

8. Inductive reactance, X_L, is equal to $2\pi FL$.

9. No power is dissipated in a pure inductance.

LESSON PLAN

RESISTANCE AND INDUCTANCE IN SERIES

OBJECTIVE:

To explain and demonstrate by means of formulas and diagrams:

1. The distinction between resistance, reactance, and impedance in ac circuits,
2. How to determine the impedance of circuits consisting of inductance and resistance in series, and
3. Power formulas for ac circuits.

INTRODUCTION:

When an ac voltage is applied to a circuit consisting of several resistors connected in series, the sum of the voltage drops across the resistors is equal to the applied voltage; but when resistors and inductors are connected in series, the simple sum of the rms voltage drops is not equal to the applied voltage. The discrepancy arises because the ac voltage drops across the resistors are not in phase with the voltage drops across the inductors. The relationship between the voltage drops will be explained in this lesson.

PRESENTATION:

1. The unit of opposition to current flow in an ac circuit is the ohm; however, the opposition may be reactive (inductive or capacitive), resistive, or combinations of resistance and reactance.
2. When the opposition to the flow of an ac current consists of resistance and reactance, the total effective opposition is called impedance. The unit of impedance is the ohm, and the symbol for impedance is Z.

3. The ac circuit shown in diagram 64 has a generator whose output is ten volts and a resistor of four ohms in series with an inductor whose reactance is three ohms.

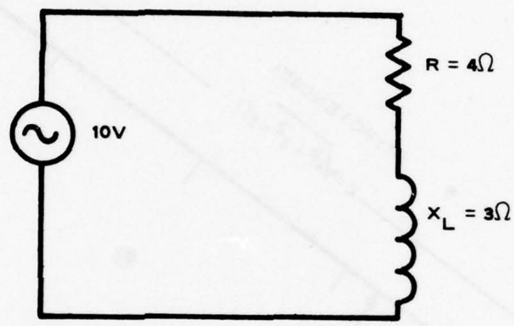

Diagram 64. AC circuit.

a. The impedance Z of the circuit in diagram 64 is calculated by assuming that R and X_L are two sides of a right triangle (diag 65). The hypotenuse of the right triangle is equal to the impedance of the circuit.

b. The hypotenuse of a right triangle is equal to the square root of the sum of the squares of the other two sides (diag 65). Likewise, the impedance of the circuit of diagram 64 is equal to the square root of the sum of the squares of the resistance, R, and inductive reactance, X_L.

$$Z = \sqrt{R^2 + (X_L)^2} \qquad (23)$$

$$= \sqrt{4^2 + 3^2}$$

$$= \sqrt{16 + 9} = \sqrt{25} = 5 \text{ ohms.}$$

c. The current that flows in any ac circuit is equal to the applied voltage divided by the impedance of the circuit; therefore, the current in the circuit of diagram 64 is calculated as shown below:

$$I = \frac{E}{Z} \qquad (24)$$

$$= \frac{10}{5} = 2 \text{ amperes}$$

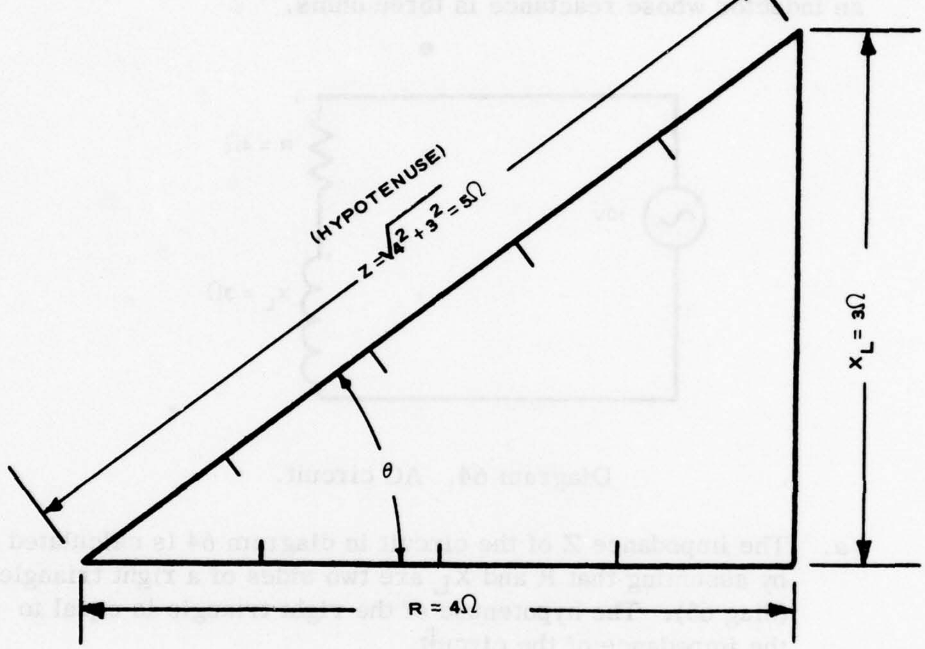

Diagram 65. Calculating Z.

d. Since the current supplied by the generator in diagram 64 is two amperes, the two-ampere current flows through both the four-ohm resistor and the three-ohm inductive reactance. The voltage that appears across the resistor and inductor may be determined as follows:

$$E_R = IR \text{ (equation (3))}$$

$$= 2 \times 4 = 8 \text{ volts, and}$$

$$E_L = IX_L \qquad (25)$$

$$= 2 \times 3 = 6 \text{ volts.}$$

e. The applied voltage, the resistor voltage, and the inductor voltage have the same relationship to one another as the relationship between impedance, resistance, and inductive reactance. The relationships are compared below.

$$E_{applied} = \sqrt{(E_R)^2 + (E_L)^2} \qquad (26)$$

$$= \sqrt{8^2 + 6^2} = \sqrt{100} = 10 \text{ volts, and}$$

$$Z = \sqrt{R^2 + (X_L)^2} \quad \text{(by equation (23))}$$

$$= \sqrt{4^2 + 3^2} = \sqrt{25} = 5 \text{ ohms.}$$

f. Ohm's law applies directly to the four-ohm resistor of diagram 64.

$$I = \frac{E_R}{R} \quad \text{(equation (1))}$$

$$2 = \frac{8}{4}$$

$$R = \frac{E_R}{I} \quad \text{(equation (2))}$$

$$4 = \frac{8}{2}$$

$$E_R = IR \quad \text{(equation (3))}$$

$$8 = 2 \times 4.$$

g. Though Ohm's law applies to the inductor, X_L must be used in the equations instead of R.

$$I = \frac{E_L}{X_L} \qquad (27)$$

$$2 = \frac{6}{3}$$

$$X_L = \frac{E_L}{I} \qquad (28)$$

$$3 = \frac{6}{2}$$

$$E_L = IX_L \qquad (29)$$

$$6 = 2 \times 3.$$

h. Though Ohm's law applies to the whole circuit, Z must be used in the equation in place of R.

$$I = \frac{E}{Z} \text{ (equation (24))}$$

$$2 = \frac{10}{2}$$

$$Z = \frac{E}{I} \qquad (30)$$

$$5 = \frac{10}{2}$$

$$E = IZ \qquad (31)$$

$$10 = 2 \times 5.$$

i. In diagram 64, the only power dissipated in the circuit will be dissipated in the resistor; no power is dissipated in a pure inductance. Any of the three power equations (4), (5), and (6) may be used to determine the power consumed:

$$P = 2^2 \times 4 = 16 \text{ watts.}$$

$$P = \frac{8^2}{4} = \frac{64}{4} = 16 \text{ watts.}$$

$$P = 8 \times 2 = 16 \text{ watts.}$$

j. The current in the circuit of diagram 64 is in phase with the voltage across the resistor, but the current lags the applied voltage by the angle θ (theta) indicated in diagram 64 because of the presence of the inductance in the circuit. Since the current is not in phase with the applied voltage, the product of applied voltage and current gives an apparent power but not the true power. The apparent power is greater than the true power (by equation (20)) which was found to be 16 watts (par 3i above). To find the true power, the

apparent power ($E_{applied}$ x I) must be multiplied by the power factor (a number that is always one or less):

$$\text{Apparent power} = E \times I$$

$$= 10 \times 2 = 20 \text{ watts.}$$

$$\text{True power} = E \times I \times pf. \qquad (32)$$

k. In a series circuit, such as diagram 64, the power factor is equal to the resistance in ohms divided by the impedance in ohms.

$$pf = \frac{R}{Z} \qquad (33)$$

$$= \frac{4}{5} = 0.8$$

$$P_{true} = 10 \times 2 \times 0.8 = 16 \text{ watts (by equation (32)).}$$

4. Diagram 66 shows four circuits to be solved for the indicated values.

> INSTRUCTOR'S NOTE: Put the circuits of diagram 66 on the blackboard, solve for required values, and ask the students to solve for other unknown values in each circuit.

5. If a circuit contains several resistors and inductive reactances in a series, the resistance may be added to find a single resistance, and the inductive reactances may be added to find a single reactance (diag 67(1)). The simplified circuit (diag 67(2)) may be solved in the same way that the circuit of diagram 64 was solved.

> INSTRUCTOR'S NOTE: Put circuits of diagram 67 on blackboard, and solve for all unknown values.

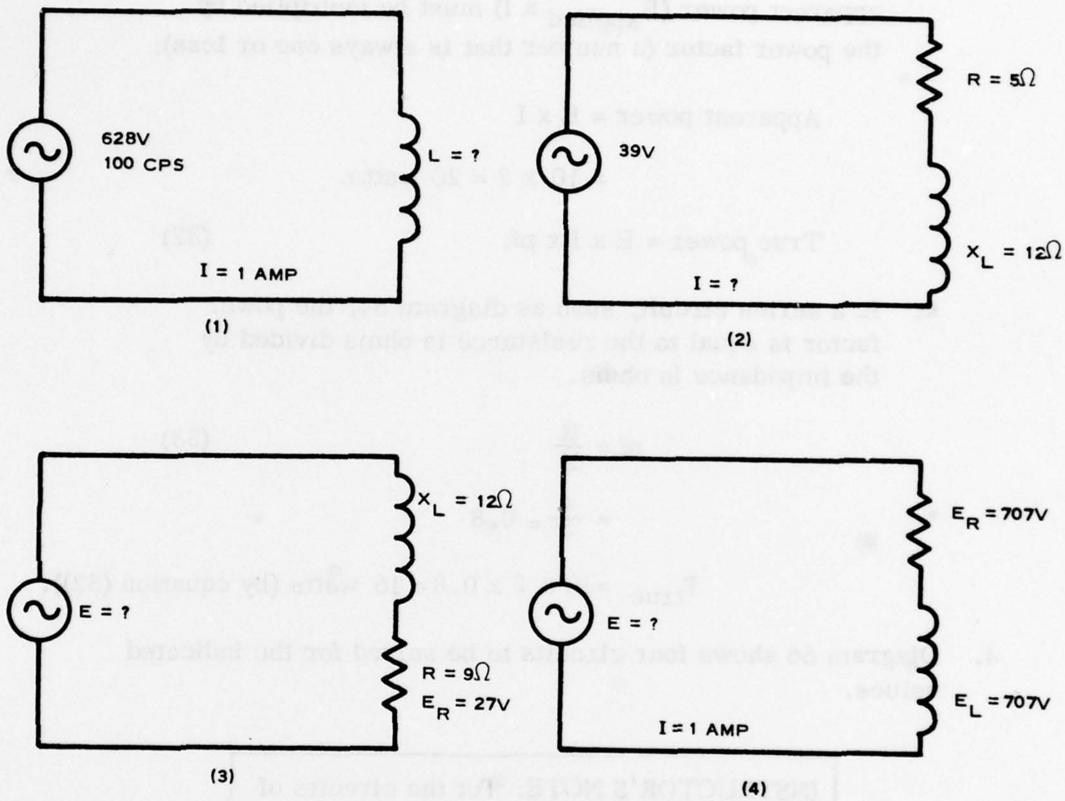

Diagram 66. Series circuit problems.

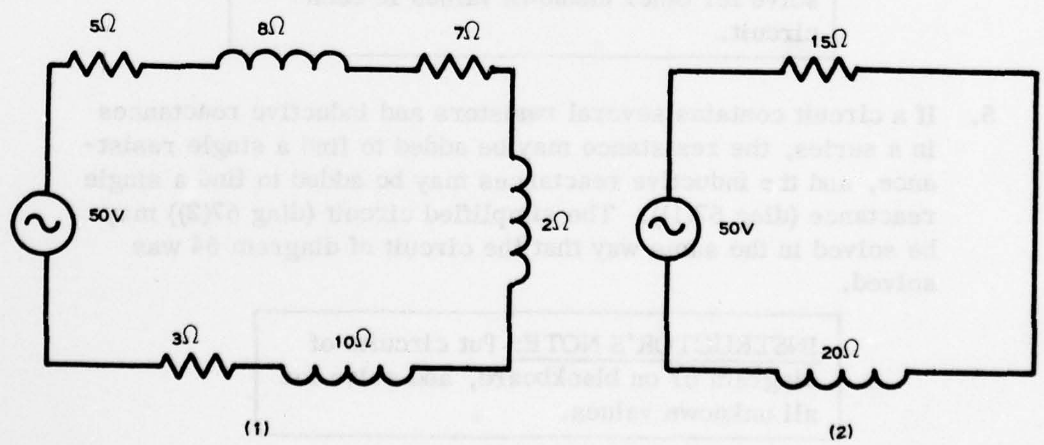

Diagram 67. Simplification of series circuit.

SUMMARY:

1. Impedance is the opposition to the flow of an alternating current, and is measured in ohms. Impedance may be resistive, reactive, or a combination of resistance and reactance.

2. The symbol for impedance is Z.

3. Impedance for a series circuit consisting of resistance and inductive reactance is calculated by equation (23):

$$Z = \sqrt{R^2 + (X_L)^2}.$$

4. The current that flows in any ac circuit is equal to the applied voltage divided by the impedance in ohms, equation (24):

$$I = \frac{E}{Z}$$

5. The applied voltage in a circuit consisting of R and X_L in series is equal to the square root of the sum of the squares of the voltage drop across the resistance and the voltage drop across the inductance by equation (26):

$$E_{applied} = \sqrt{(E_R)^2 + (E_L)^2}.$$

   a. The voltage drop across the resistor is equal to the current multiplied by the resistance in ohms by equation (3):

$$E_R = IR.$$

   b. The voltage drop across the inductance is equal to the current multiplied by the inductive reactance by equation (25):

$$E_L = IX_L.$$

6. No power is dissipated in a pure inductance.

7. Power is dissipated in any resistor according to the equations (5) and (6):

$$P = I^2R \text{ and } P = \frac{(E_R)^2}{R}.$$

8. The power supplied by an ac generator is equal to the apparent power (E x I) multiplied by the power factor, equation (32):

$$P = E_{app} \times I \times pf.$$

9. The power factor of a series ac circuit is equal to the resistance divided by the impedance by equation (33):

$$pf = \frac{R}{Z}.$$

10. If a series circuit contains several resistors and inductors, the circuit is simplified for calculation purposes by adding the resistances to obtain one resistance value and adding the inductive reactances to obtain one reactance value. The simplified circuit is solved for the one resistance (total) and the one inductive reactance (total).

LESSON PLAN

RESISTANCE AND INDUCTANCE IN PARALLEL

OBJECTIVE:

To explain and demonstrate by means of diagrams:

1. How to determine the impedance of circuits consisting of resistance and inductance in parallel,
2. How to calculate power dissipated in a parallel R-L circuit, and
3. How to determine the power factor in a parallel R-L circuit.

INTRODUCTION:

1. The current in series ac circuits is the same in all parts of the circuit, but in parallel circuits the current may be different in each of the parallel branches. In the parallel circuit the voltage is the same across all branches.

2. The most convenient method of determining the impedance of R and L in parallel is by the indirect method in which the total line current is calculated; the line voltage (generator voltage) is then divided by the line current to find the circuit impedance. The method is explained in detail in this lesson.

PRESENTATION:

1. When an ac generator is connected to a parallel circuit consisting of two resistors, the line current (generator current) is equal to the simple sum of the branch currents as shown in diagram 68.

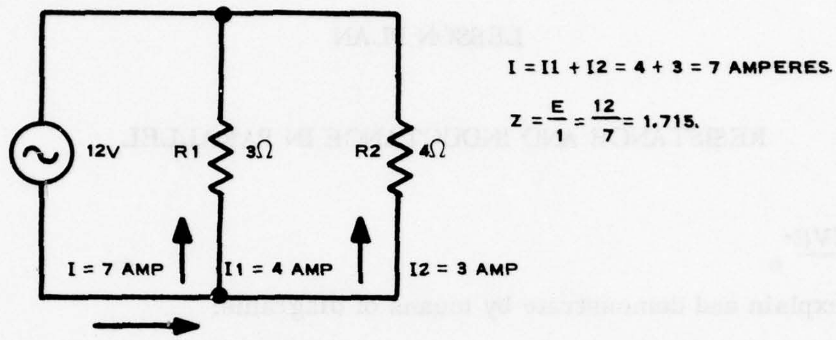

Diagram 68. Resistors in parallel.

2. The line current in diagram 68 is 7 amperes (3 + 4), and the impedance of the circuit is equal to the line voltage (12 volts) divided by the line current (7 amperes), equation (30):

$$Z = \frac{12}{7} = 1.714 \text{ ohms.}$$

3. In diagram 69 an inductive reactance of four ohms has been substituted for the four-ohm resistor in diagram 68. The resistive and reactive currents are four and three amperes, respectively. Because of the phase difference between the two branch currents (I_R in phase with line voltage and I_L lagging the line voltage by 90°) the line current is equal to the square root of the sum of the squares of the branch currents:

$$I = \sqrt{(I_R)^2 + (I_L)^2} \qquad (34)$$

$$= \sqrt{4^2 + 3^2} = \sqrt{25} = 5 \text{ amperes.}$$

4. The impedance of the parallel circuit shown in diagram 69 is equal to the line voltage divided by the line current, equation (30):

$$Z = \frac{E}{I}$$

$$= \frac{12}{5} = 2.4 \text{ ohms.}$$

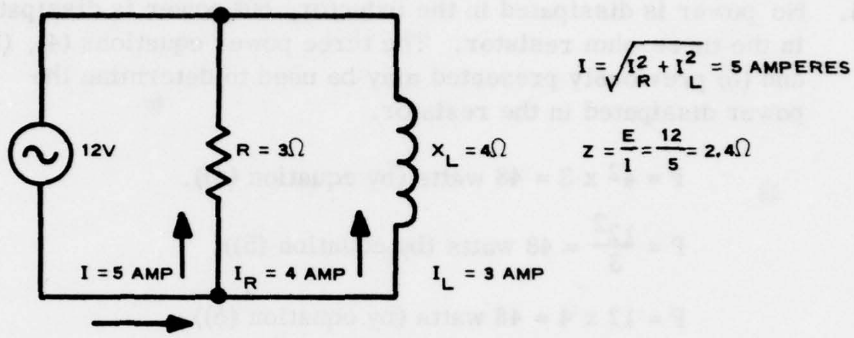

Diagram 69. R and L in parallel.

5. It will be noted that the equation used to determine the line current is similar to the equation used to determine the total impedance of a series circuit. When using equation (34), $I = \sqrt{(I_R)^2 + (I_L)^2}$, I is called the vector sum of I_R and I_L; and I is the hypotenuse of a right triangle of which I_R and I_L are the other two sides. The vector addition of I_R (four amperes) and I_L (three amperes) is shown in diagram 70.

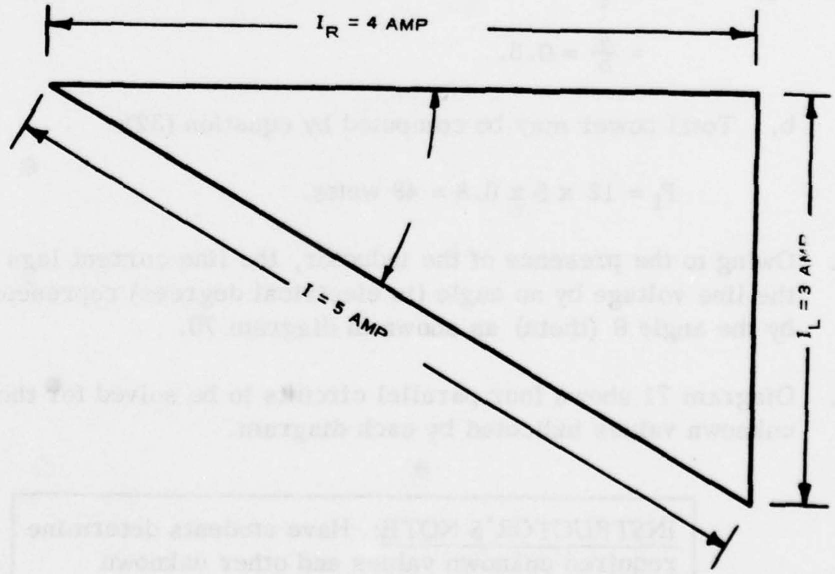

Diagram 70. Vector addition of currents.

6. No power is dissipated in the inductor, but power is dissipated in the three-ohm resistor. The three power equations (4), (5), and (6) previously presented may be used to determine the power dissipated in the resistor.

$P = 4^2 \times 3 = 48$ watts (by equation (4)).

$P = \frac{12^2}{3} = 48$ watts (by equation (5)).

$P = 12 \times 4 = 48$ watts (by equation (6)).

7. The total power supplied by the generator (diag 69) is 48 watts as calculated above, since power is dissipated only in the resistor. As a check, however, total power may be found by computing the product of generator voltage, generator current, and power factor (equation (32)): $P = IE \times pf$.

   a. Since the power factor of the parallel circuit is equal to the resistive current divided by the line current:

$$pf = \frac{I_R}{I} \qquad (35)$$

$$= \frac{4}{5} = 0.8.$$

   b. Total power may be computed by equation (32):

$P_t = 12 \times 5 \times 0.8 = 48$ watts.

8. Owing to the presence of the inductor, the line current lags the line voltage by an angle (in electrical degrees) represented by the angle θ (theta) as shown in diagram 70.

9. Diagram 71 shows four parallel circuits to be solved for the unknown values indicated by each diagram.

> <u>INSTRUCTOR'S NOTE</u>: Have students determine required unknown values and other unknown values as time permits.

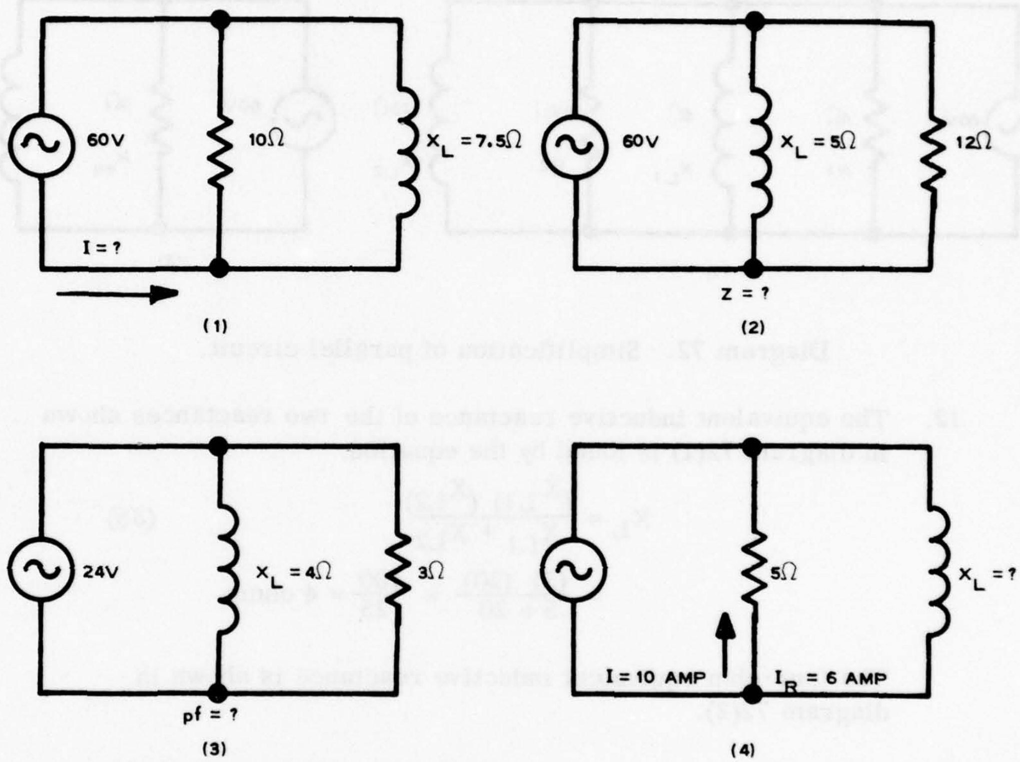

Diagram 71. Parallel circuit problems.

10. When a parallel circuit contains several resistors and several inductive reactances in parallel, both the resistors and inductive reactances may be combined to give an equivalent parallel circuit consisting of one resistor and one inductive reactance.

11. Diagram 72(1) shows a parallel circuit which has two resistors, 4 ohms, and 12 ohms, in parallel. The equivalent resistance is found by equation (9):

$$R_{eq} = \frac{R1\ R2}{R1 + R2}$$

$$= \frac{(4)\ (12)}{4 + 12} = \frac{48}{16} = 3 \text{ ohms.}$$

The three-ohm equivalent resistance is shown in diagram 72(2).

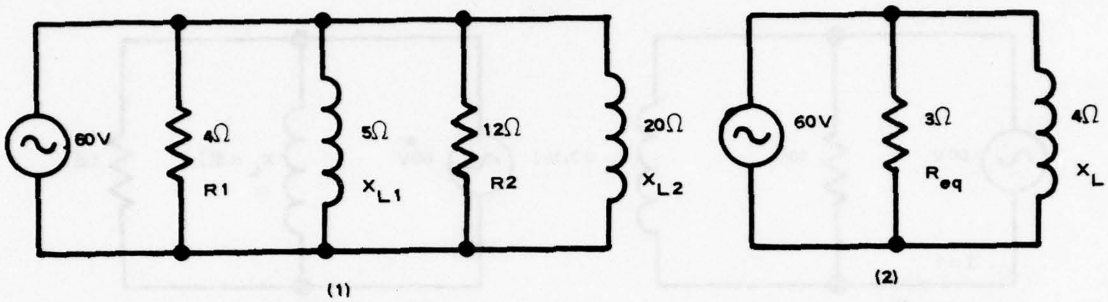

Diagram 72. Simplification of parallel circuit.

12. The equivalent inductive reactance of the two reactances shown in diagram 72(1) is found by the equation:

$$X_L = \frac{(X_{L1})\ (X_{L2})}{X_{L1} + X_{L2}} \tag{36}$$

$$= \frac{(5)\ (20)}{5 + 20} = \frac{100}{25} = 4 \text{ ohms.}$$

The four-ohm equivalent inductive reactance is shown in diagram 72(2).

13. The equivalent circuit shown in diagram 72(2) is solved by the same method used on the parallel circuit of diagram 69.

SUMMARY:

1. The line current of a circuit consisting of R and L in parallel is equal to the vector sum of the branch currents (by equation (34)):

$$I = \sqrt{(I_R)^2 + (I_L)^2}.$$

2. The branch currents of a circuit consisting of R and L in parallel are found by dividing the applied voltage by the branch impedances:

$$I_R = \frac{E}{R} \text{ (equation (1))}$$

$$I_L = \frac{E}{X_L} \text{ (equation (27)).}$$

3. The voltage is the same across all branches of a parallel circuit.

4. The impedance of a circuit consisting of R and L in parallel is equal to the line voltage divided by the line current by equation (30):

$$Z = \frac{E}{I}$$

5. The power factor of a circuit consisting of R and L in parallel is equal to the resistor current divided by the line current by equation (35):

$$pf = \frac{I_R}{I}.$$

6. No power is dissipated in a pure inductance.

7. The power dissipated in a resistor may be found by any of the three power formulas (4), (5), and (6):

$$P = I^2R,\ P = \frac{E^2}{R},\ \text{or } P = IE.$$

8. The power supplied by an ac generator to any circuit may be found by equation (32):

$$P = EI \times pf.$$

LESSON PLAN

CAPACITANCE

OBJECTIVE:

To explain and demonstrate:

1. The physical construction of a capacitor,
2. The electrical properties of a capacitor, and
3. How to calculate capacitive reactance.

INTRODUCTION:

1. The electrical properties of capacitors are extremely important in the study of electronics because, for example, when associated with inductors, capacitors make possible the phenomenon of resonance. Resonant circuits are utilized in practically all circuits where specific ac frequencies must be produced, guided, and/or radiated into space as radio waves.

2. Capacitors are very frequently used to couple (transfer) signals from one circuit to another. Since the circuits to be coupled may be at different dc voltages with respect to ground, a capacitor is used to pass the ac voltages and to prevent the passage of dc voltages.

PRESENTATION:

1. Diagram 73 shows the physical construction of a capacitor. This example shows six square metal plates; three of which (the even-numbered plates) are connected to terminal X and the rest (the odd-numbered plates) connected to terminal Y. The plates are insulated from one another, and there is no metallic connection from terminal X to terminal Y through the capacitor.

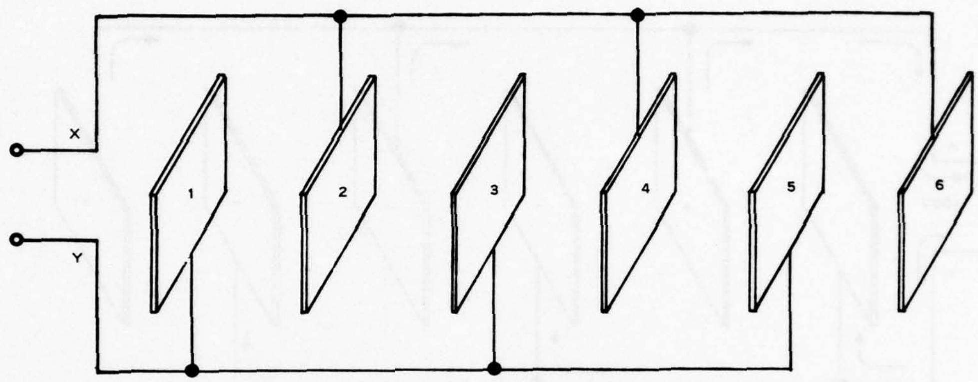

Diagram 73. Basic capacitor.

2. If a battery is connected to terminals X and Y as shown in diagram 74, a current will flow for a very short time but will stop flowing when the capacitor has charged to a voltage equal to the battery voltage.

3. At the first instant when the battery is connected, the current flow (arrows in diag 74) is limited only by the resistance of the connecting wires; but as current flows, a surplus of electrons accumulates on the plates marked with the minus sign, and a deficiency of electrons occurs on the plates marked with the plus sign.

4. As a greater surplus of electrons accumulates on the negative plates (minus sign), and a greater deficiency of electrons occurs on the positive plates (plus sign), the voltage difference between the two sets of plates increases, and the current flow decreases. Then the voltage difference between the two sets of plates becomes equal to the battery voltage, the current flow is zero.

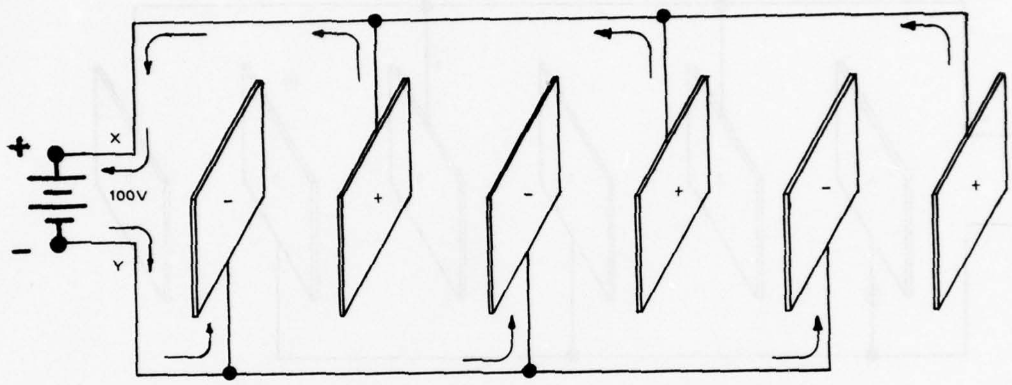

Diagram 74. Charged capacitor.

INSTRUCTOR'S NOTE: The charging current flowing into a capacitor may be illustrated by charging an 8-microfarad capacitor from the 350v power supply through the voltmeter on the classroom console. Use the 500v setting on the voltmeter. Obtain the eight microfarad, paper, dielectric capacitor, and connecting leads from the Training Aids Section.

5. When the capacitor of diagram 74 is charged, there will exist between the oppositely charged plates an *electrostatic field*. The energy supplied by the battery during the charging time is stored in *this field*.

6. If the battery is disconnected from the capacitor after the charging process, the voltage between terminals X and Y of diagram 74 will remain as long as the deficiency of electrons on one set of plates and the corresponding excess of electrons on the other plates exists.

7. If a current path, such as a metal wire, is connected between the capacitor terminals, the capacitor will discharge by means of a current flow from the negative plates to the positive plates. Discharging the capacitor allows the surplus of electrons on the negative plates to move around the circuit to the positive plates, equalizing the electron content of each set of plates.

> INSTRUCTOR'S NOTE: Illustrate the discharge of the capacitor in two ways: first, by shorting the capacitor with a wire lead, and second, by allowing the capacitor to discharge through the 500v voltmeter.

8. The voltage across a capacitor cannot change instantly, and an interval of time is always required for current to flow to either charge or discharge the capacitor. This indicates that there is always a delay in the rise or fall of voltage and that current must be flowing before the voltage change can occur.

9. The greater the area of the capacitor plates, the more current that must flow to charge the capacitor to a given voltage.

10. If the total plate area of a capacitor is great enough so that a current of one ampere must flow for one second to produce a voltage difference of one volt between the plates, the capacitor, by definition, has a capacity of one farad.

11. The more practical units of capacity in electronics are the microfarad (one-millionth of a farad: μf) and the micromicrofarad one-millionth of one-millionth of a farad: μμf).

12. When an ac generator is connected to a capacitor, as shown in diagram 75, a current will flow in the circuit to charge and discharge the capacitor, but no current will actually flow through the insulation between the plates.

13. As stated in paragraph 8, there is a delay in the rise of voltage with respect to the charging current or in the fall of voltage with respect to the discharge current. Therefore, when an ac voltage

is applied to a capacitor, the sine wave of current must lead the sine wave of voltage (diag 76) by 90 electrical degrees. (It should be recalled that the current through an inductor lagged the voltage by 90 electrical degrees.)

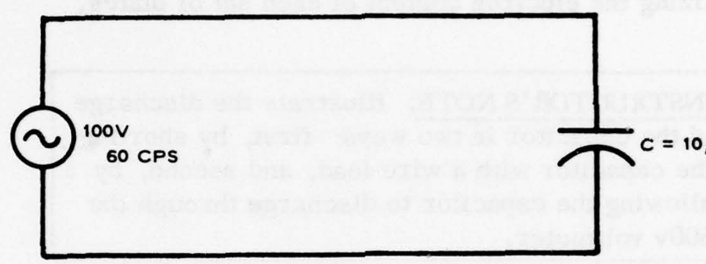

Diagram 75. Capacitor with ac applied.

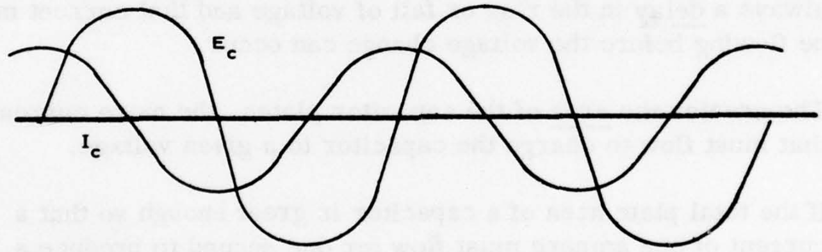

Diagram 76. I_C leading E_C by 90°.

14. A capacitor is a reactance, and a reactance consumes no power. In comparing a capacitor to an inductor (which is also a reactance), they have certain characteristics in common.

a. Both store electrical power during part of an ac cycle.

b. Both return power to the circuit during another part of the ac cycle.

c. The inductor stores power in the magnetic field, but when the current decreases to zero, the magnetic field collapses and returns the stored power to the circuit.

d. The capacitor stores power in the electrostatic field between the plates, but when the voltage decreases to zero, the power is returned to the circuit.

e. In the case of either kind of reactance, the net power taken fron the generator is zero.

f. In contrast, a resistor returns no power to the circuit since all power received from the generator is dissipated as heat.

15. The current which flows in a capacitor varies inversely with the capacitive reactance which is measured in ohms.

16. The capacitive reactance may be calculated by the equation:

$$X_C = \frac{1}{2 \pi FC} \qquad (37)$$

X_C = Reactance in ohms.

F = Frequency in cycles per second.

C = Capacity in farads.

π = 3.1416.

17. Ohm's law applies to a capacitor according to the equation:

$$I_c = \frac{E_c}{X_C}. \qquad (38)$$

SUMMARY:

1. A capacitor passes ac current but blocks dc current.
2. A capacitor tends to oppose a change of voltage across itself.
3. The voltage across a capacitor cannot change instantly.
4. A capacitor dissipates no power.
5. Capacitive reactance decreases as the frequency of the applied voltage increases.
6. The capacitance of any capacitor depends on the total area of the plates, the distance between the plates, and the kind of insulating material between the plates.

LESSON PLAN

RESISTANCE AND CAPACITANCE IN SERIES

OBJECTIVE:

To explain and demonstrate:

1. The effects of capacitance and resistance on the phase angle of current in a series RC circuit,
2. How to calculate the impedance of a series RC circuit,
3. How to calculate the power dissipated in a series RC circuit, and
4. How to determine the power factor of a series RC circuit.

INTRODUCTION:

The solution of the series RC circuit is the same as the solution of the series RL circuit. The only difference between the two circuits is in their effect on the phase angle of the current. It was found in the series RL circuits that the line current always lagged the line voltage, but in the series RC circuits the line current always leads the applied voltage (diag 77).

PRESENTATION:

1. The simple RC circuit of diagram 78 has a 12-ohm resistor in series with a capacitor whose reactance (at the generator frequency) is 9 ohms. The impedance of the circuit is determined by the equation:

$$Z \quad \sqrt{R^2 + (X_C)^2} \qquad (39)$$

$$= \sqrt{12^2 + 9^2} = \sqrt{144 + 81} = \sqrt{225} = 15 \text{ ohms.}$$

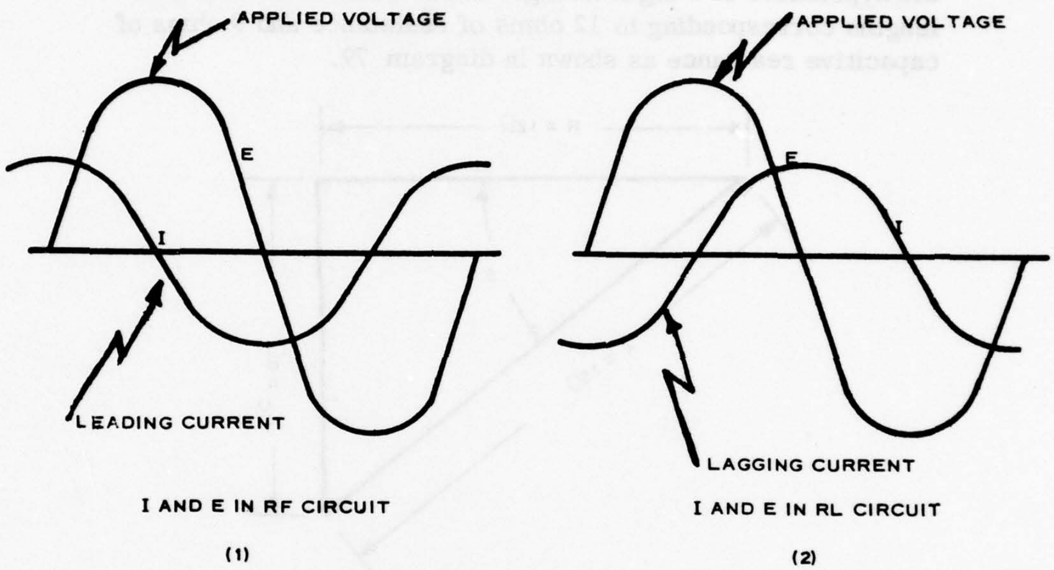

Diagram 77. I and E relations in ac circuits.

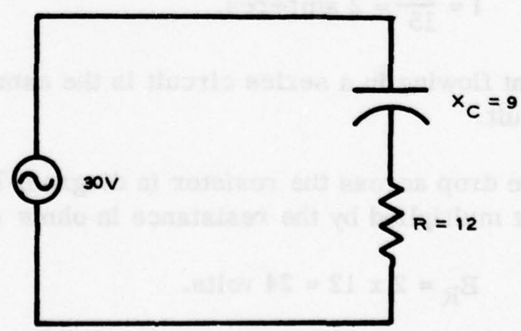

Diagram 78. Series ac circuit.

2. The impedance of the circuit of diagram 78 is equivalent to the hypotenuse of a right triangle whose other two sides have lengths corresponding to 12 ohms of resistance and 9 ohms of capacitive reactance as shown in diagram 79.

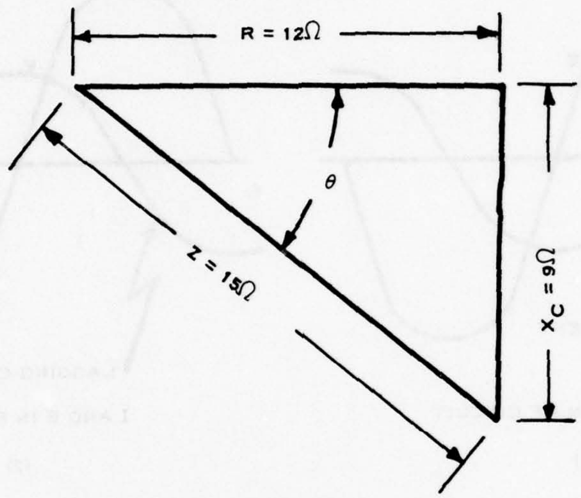

Diagram 79. Impedance diagram.

3. The current that flows in the circuit of diagram 78 is equal to the applied voltage divided by the impedance of the circuit equation (24):

$$I = \frac{30}{15} = 2 \text{ amperes.}$$

4. The current flowing in a series circuit is the same in all parts of the circuit.

5. The voltage drop across the resistor in diagram 78 is equal to the current multiplied by the resistance in ohms equation (3):

$$E_R = 2 \times 12 = 24 \text{ volts.}$$

6. The voltage drop across the capacitor in diagram 78 is equal to the current times the capacitive reactance:

$$E_C = IX_C \qquad (40)$$

$$= 2 \times 9 = 18 \text{ volts.}$$

7. The applied voltage of the circuit of diagram 78 is equal to the vector sum of the resistive and reactive voltage drops:

$$E = \sqrt{(E_R)^2 + (E_C)^2} \qquad (41)$$

$$= \sqrt{24^2 + 18^2} = \sqrt{576 + 324} = \sqrt{900} = 30 \text{ volts.}$$

8. The current in the circuit of diagram 78 leads the applied voltage by the angle θ (theta) shown on the vector diagram of diagram 79.

9. The power factor of the circuit in diagram 78 is equal to the resistance in ohms divided by the impedance in ohms, equation (33):

$$pf = \frac{12}{15} = 0.8.$$

10. The power supplied by the generator in the circuit of diagram 78 is equal to the line voltage (generator voltage) times the line current (generator current) times the power factor, equation (32):

$$P = EI \times pf = 30 \times 2 \times 0.8 = 48 \text{ watts.}$$

11. No power is dissipated in the capacitor, but power is dissipated in the resistor, and the power dissipated in the resistor should be the same as calculated in paragraph 10. Any of the three power equations for resistors may be used:

a. $P = 2^2 \times 12 = 4 \times 12 = 48$ watts,

b. $P = \frac{24^2}{12} = \frac{546}{12} = 48$ watts, or

c. $P = 24 \times 2 = 48$ watts.

12. Diagram 80 shows four exercise problems to be solved. Find the unknown quantities indicated on each circuit diagram.

> INSTRUCTOR'S NOTE: Put the circuits of diagram 80 on the blackboard, and have the students solve for required unknown quantities; then have students solve for other unknown quantities if time permits.

SUMMARY:

1. Impedance for a series RC circuit is calculated by equation (39):

$$Z = \sqrt{R^2 + (X_C)^2}$$

2. The applied voltage in a circuit consisting of R and X_C in series is equal to the square root of the sum of the squared resistive and reactive voltage drops, equation (41):

$$E = \sqrt{(E_R)^2 + (E_C)^2}$$

3. No power is dissipated in the capacitor.

4. Power is dissipated in the resistors according to equations (4), (5), or (6).

5. The power factor of a series RC circuit is equal to the resistance in ohms divided by the impedance in ohms, equation (33):

$$pf = \frac{R}{Z}$$

6. If a series circuit, such as is shown in diagram 81(1), consists of several resistors and capacitors, the circuit may be simplified as shown in diagram 81(2) by adding resistances and by adding capacitive reactances. The simplified circuit (diag 81(2)) may then be solved for all unknown quantities.

INSTRUCTOR'S NOTE: Put the circuit of diagram 81(1) on the blackboard, and explain in detail how to simplify the circuit. Emphasize that capacitances in series cannot be added, but capacitive reactances in series can be added.

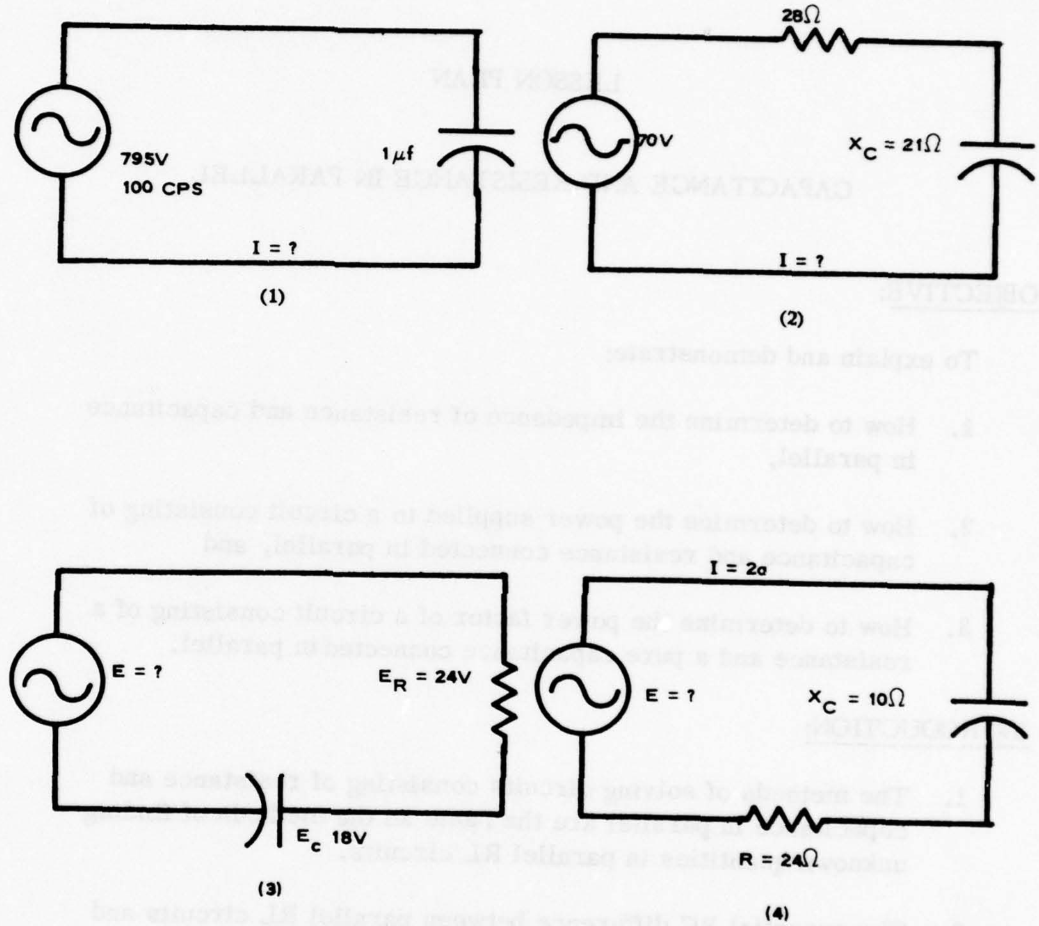

Diagram 80. RC circuit problems.

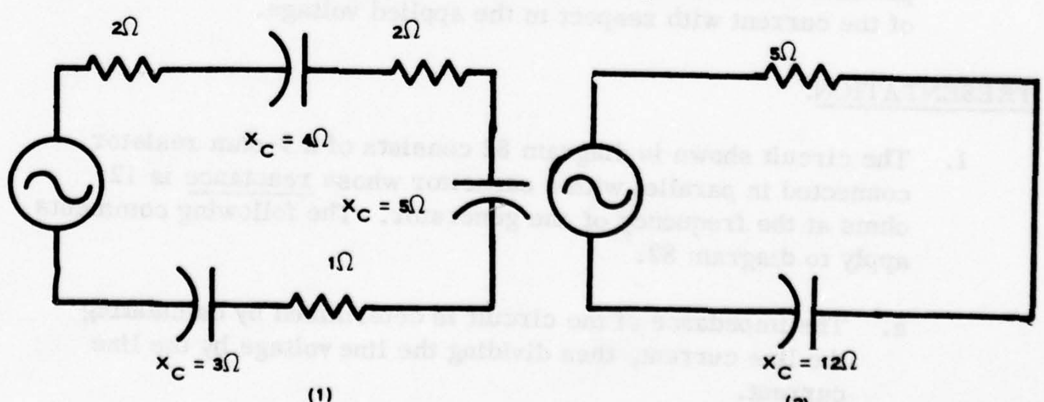

Diagram 81. Simplifying RC series circuits.

LESSON PLAN

CAPACITANCE AND RESISTANCE IN PARALLEL

OBJECTIVE:

To explain and demonstrate:

1. How to determine the impedance of resistance and capacitance in parallel,

2. How to determine the power supplied to a circuit consisting of capacitance and resistance connected in parallel, and

3. How to determine the power factor of a circuit consisting of a resistance and a pure capacitance connected in parallel.

INTRODUCTION:

1. The methods of solving circuits consisting of resistance and capacitance in parallel are the same as the methods of finding unknown quantities in parallel RL circuits.

2. The essential RC difference between parallel RL circuits and parallel RC circuits is the effect of L and C on the phase angle of the current with respect to the applied voltage.

PRESENTATION:

1. The circuit shown in diagram 82 consists of a 9-ohm resistor connected in parallel with a capacitor whose reactance is 12 ohms at the frequency of the generator. The following comments apply to diagram 82.

   a. The impedance of the circuit is determined by calculating the line current, then dividing the line voltage by the line current.

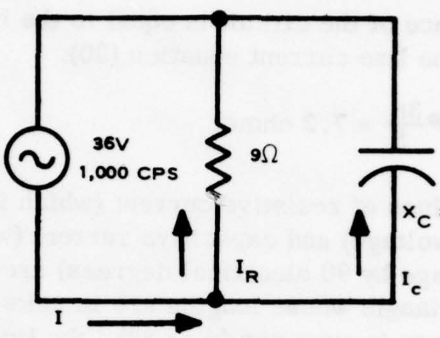

Diagram 82. Parallel RC circuit.

INSTRUCTOR'S NOTE: Put the circuit of diagram 82 on the blackboard. Emphasize the fact that the impedance of the circuit is not the vector sum of the impedance of the branches. Explain that the vector sum of impedances is applicable only to series circuits.

b. The current through the resistor is equal to the line voltage divided by the resistance in ohms, equation (1):

$$I_R = \frac{36}{9} = 4 \text{ amperes.}$$

c. The current through the capacitor is equal to the line voltage divided by the reactance of the capacitor, equation (38):

$$I_c = \frac{E}{X_C} = \frac{36}{12} = 3 \text{ amperes.}$$

d. The line current is equal to the vector sum of the branch currents. (The line current is equal to the square root of the sum of the squares of the branch currents.)

$$I = \sqrt{(I_R)^2 + (I_c)^2} \qquad (42)$$

$$= \sqrt{4^2 + 3^2} = \sqrt{16 + 9} = \sqrt{25} = 5 \text{ amperes}$$

e. **The impedance of the circuit is equal to the line voltage divided by the line current equation (30):**

$$Z = \frac{36}{5} = 7.2 \text{ ohms.}$$

f. **When the values of resistive current (which is in phase with the applied voltage) and capacitive current (which leads the applied voltage by 90 electrical degrees) are drawn as sides of a right triangle whose lengths are in units corresponding to the currents in amperes (diag 83), the line current corresponds to the length of the hypotenuse of the right triangle.**

g. **The angle in electrical degrees by which the line current leads the line voltage is the same as the angle θ indicated in diagram 83.**

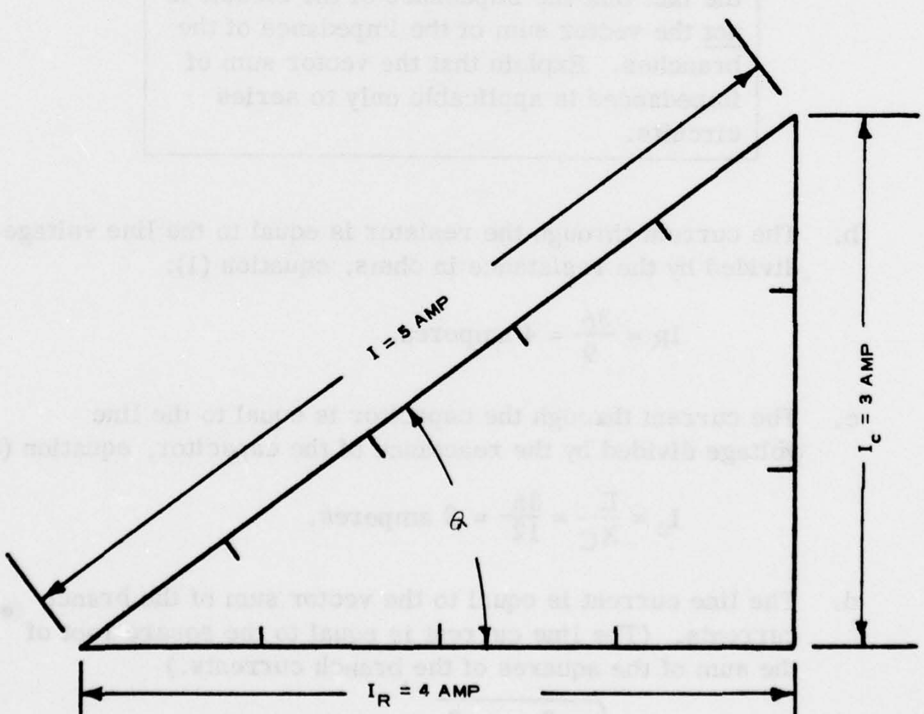

Diagram 83. Parallel circuit currents.

h. The power factor of the circuit is equal to the resistance current (I_R of the resistive branch) divided by the line current equation (35):

$$pf = \frac{4}{5} = 0.8.$$

i. The true power delivered by the generator is equal to the apparent power (I x E), multiplied by the power factor, equation (32):

$$P = 36 \times 5 \times 0.8 = 144 \text{ watts.}$$

j. Since the only power dissipated in the circuit is that dissipated in the resistor, the power may be calculated by any of the three power equations for resistors.

1) $P = 36 \times 4 = 144$ watts.

2) $P = 4^2 \times 9 = 16 \times 9 = 144$ watts.

3) $P = \frac{36^2}{9} = \frac{1296}{9} = 144$ watts.

2. Diagram 84 contains four parallel circuits as exercise problems. Solve each one for the indicated unknown quantities.

> <u>INSTRUCTOR'S NOTE</u>: Have the students solve the problems in diagram 84 for the required unknown quantities, but also have the students solve the same problems for other unknown quantities as time allows.

3. If a parallel circuit contains several parallel branches such as those shown in diagram 85(1), the resistive branches may be combined to produce a resultant resistance as is shown in diagram 85(2). The capacitive reactances shown in diagram 85(1) may also be combined to produce a single reactance as shown in diagram 85(2).

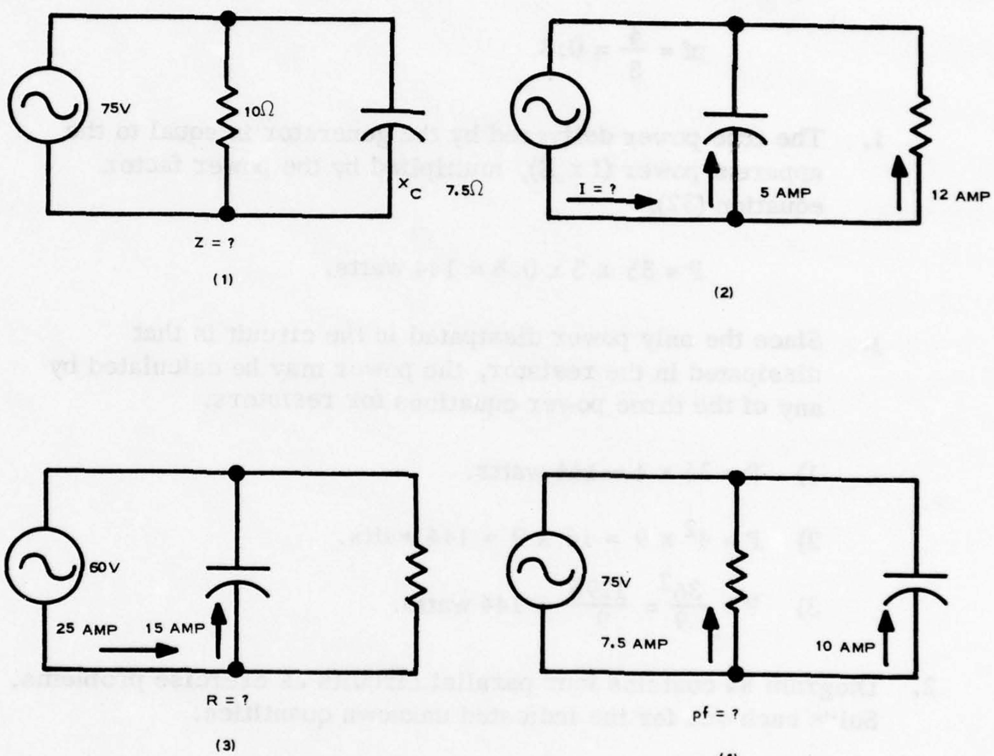

Diagram 84. Parallel circuit problems.

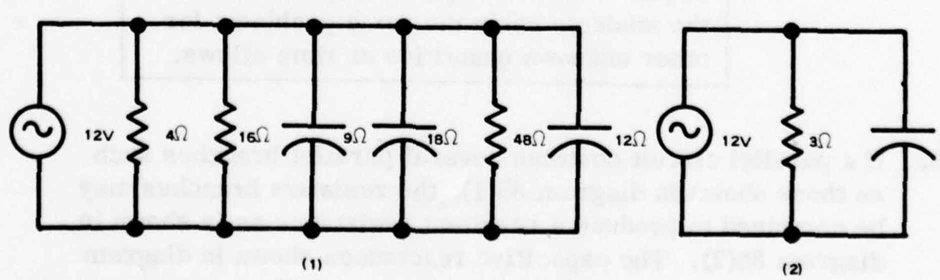

Diagram 85. Simplification of parallel circuits.

INSTRUCTOR'S NOTE: Solve the circuit of diagram 85(2) (use blackboard) for line current, then solve the circuit of diagram 85(1) for all branch currents. Show that the vector sum of branch currents in 85(1) is equal to line current of 85(2).

SUMMARY:

1. The line current of a circuit consisting of R and C in parallel is equal to the vector sum of the branch currents, equation (42):

$$I = \sqrt{(I_p)^2 + (I_c)^2}$$

2. The impedance of the parallel RC circuit by equation (30) is:

$$Z = \frac{E}{I}$$

3. The power factor of the circuit is equal to the current in the resistive branch divided by the line current, equation (35):

$$Pf = \frac{I_R}{I}$$

4. No power is dissipated in the capacitor.

5. The power dissipated in the resistor can be found by any of the three power equations, (4), (5), or (6).

6. The true power delivered by a generator to any circuit by equation (32) is:

$$P = IE \times pf$$

LESSON PLAN

R, L, AND C IN SERIES

OBJECTIVE:

To explain and demonstrate:

1. The effects of inductance and capacitance on one another when connected in series,

2. How the impedance of series circuits containing R, L, and C varies when the frequency of the ac generator is changed,

3. The characteristics of a series resonant circuit, and

4. How to determine the resonant frequency of any series LC combination.

INTRODUCTION:

The peculiar characteristics of circuits consisting of R, L, and C in series make possible the advanced selectivity circuits used in radio and radar. These series combinations of R, L, and C (together with parallel combinations, to be discussed in another lesson) enable us to carefully isolate and control the frequencies we want to manipulate.

PRESENTATION:

1. Diagram 86(1) shows a series RL circuit in which the 100v generator has a frequency of 500 cycles per second, the reactance of L is 10 ohms, and R is 10 ohms. The impedance of the circuit, by equation (23), is:

$$Z = \sqrt{10^2 + 10^2} = \sqrt{200} = 14.14 \text{ ohms.}$$

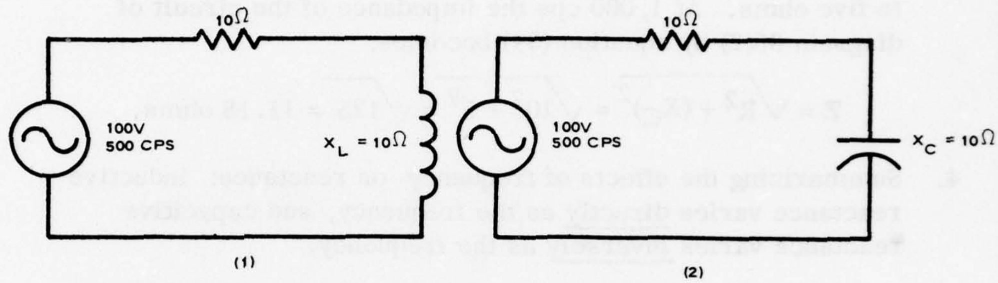

Diagram 86. Comparison of series circuits.

2. If the frequency of the generator in diagram 86(1) were increased to 1,000 cps (doubled), the reactance of L would increase to 20 ohms (doubled) because of the relationship, equation (22):

$$X_L = 2\pi FL$$

When the frequency is doubled (changed from 500 cps to 1,000 cps), the impedance of the circuit increases and, by equation (23), becomes:

$$Z = \sqrt{R^2 + (X_L)^2} = \sqrt{10^2 + 20^2} = \sqrt{500} = 22.36 \text{ ohms.}$$

> INSTRUCTOR'S NOTE: The point to emphasize in paragraph 2 is that the inductive reactance increased when the frequency of the generator increased, and the impedance of the circuit increased because X_L increased.

3. In contrast to the circuit of diagram 86(1), the circuit of diagram 86(2) (which has R = 10 ohms and X_C = 10 ohms) will have a lower impedance when the generator frequency is increased from 500 cps to 1,000 cps because of equation (37):

$$X_C = \frac{1}{2 \cdot \pi FC}.$$

When the frequency is doubled, the reactance of C decreases to five ohms. At 1,000 cps the impedance of the circuit of diagram 86(2) by equation (39) becomes:

$$Z = \sqrt{R^2 + (X_C)^2} = \sqrt{10^2 + 5^2} = \sqrt{125} = 11.18 \text{ ohms.}$$

4. Summarizing the effects of frequency on reactance: inductive reactance varies directly as the frequency, and capacitive reactance varies inversely as the frequency.

5. In diagram 87(1), the circuit shown has R, L, and C all in a series. *When an inductive reactance is in series with a capacitive reactance, the two kinds of reactance tend to cancel one another.* In diagram 87(1), the 5 ohms inductive reactance cancels 5 ohms of the 20 ohms of capacitive reactance so that, as far as the generator is concerned, the circuit of diagram 87(1) consists only of the components shown in diagram 87(2). The impedance of the circuit of diagram 87(1) may be found by the equation:

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \qquad (43)$$

$$= \sqrt{10^2 + (5 - 20)^2} = \sqrt{10^2 + (-15)^2} = \sqrt{100 + 225}$$

$$= \sqrt{325} = 18.03 \text{ ohms.}$$

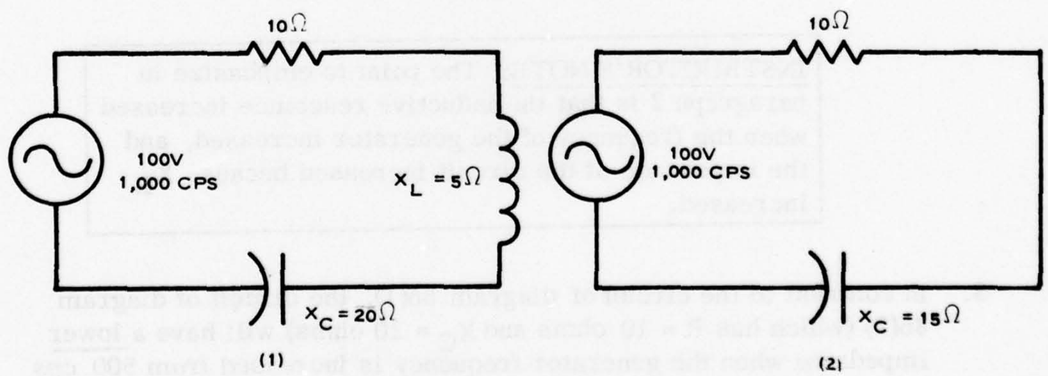

Diagram 87. Series RLC circuit.

6. The circuit of diagram 87(1) may be solved just as though the circuit were actually composed of the components shown in diagram 87(2). Using the circuit of 87(2), the calculated

values of impedance, line current, power, power factor, and phase angle will apply to the circuit of diagram 87(1).

7. If the frequency of the generator in diagram 87(1) is increased to 2,000 cps (doubled), the reactance of L will increase to 10 ohms (doubled) while the reactance of C will decrease to 10 ohms (halved). At the new frequency of 2,000 cps, the inductive reactance and the capacitive reactance are both 10 ohms, and they will cancel one another completely (diag 88(1)).

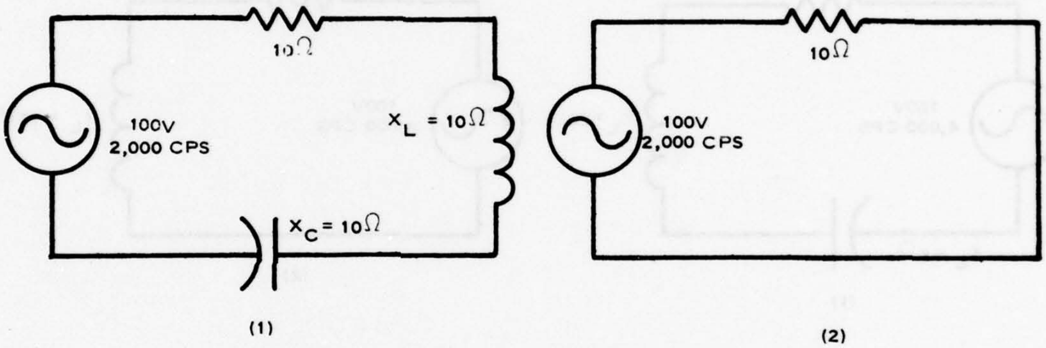

Diagram 88. Equivalent circuits at 2,000 cps.

As far as the generator is concerned, the circuit of diagram 88(1) is the same as the circuit of diagram 88(2), and the only opposition to the flow of current in the circuit is the ten-ohm resistor. The impedance equation for the circuit of diagram 88(1) by equation (43) is:

$$Z = \sqrt{10^2 + (10 - 10)^2} = \sqrt{10^2} = 10 \text{ ohms.}$$

8. The circuit of diagram 88(1) is a series resonant circuit, and the condition of resonance occurs only at the frequency at which X_L is equal to X_C.

9. If the frequency of the generator in diagram 88(1) is increased to 4,000 cps, the reactance of L increases to 20 ohms, and the reactance of C decreases to 5 ohms as shown in diagram 89(1). As far as the generator is concerned the circuit of diagram

89(1) becomes the equivalent circuit of diagram 89(2), and the impedance of the circuit may be calculated by equation (43):

$$Z = \sqrt{10^2 + (20 - 5)^2}$$
$$= \sqrt{10^2 + 15^2} = \sqrt{100 + 225}$$
$$= \sqrt{325} = 18.03 \text{ ohms.}$$

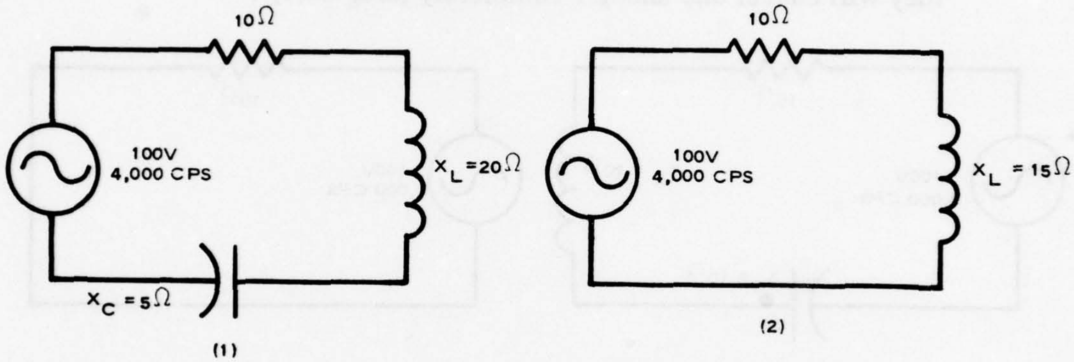

Diagram 89. Equivalent circuits at 4,000 cps.

10. The line currents that flow in each of the three circuits shown in diagrams 87, 88, and 89 may be calculated by equation (24):

a. Diagram 87: $I = \frac{E}{Z} = \frac{100}{18.03} = 5.546$ amperes,

b. Diagram 88: $I = \frac{E}{Z} = \frac{100}{10} = 10$ amperes, and

c. Diagram 89: $I = \frac{E}{Z} = \frac{100}{18.03} = 5.546$ amperes.

The important fact to be noticed in the foregoing is that the resonant circuit (diag 88) had the highest current flow because the impedance was lowest and equal to the resistance of the circuit only. The other two circuits passed a lower value of current because the impedances were higher.

11. The curves shown in diagram 90 show how the relative values of current and impedance change as the frequency of the applied voltage varies over a range from far below resonance to much higher than resonance.

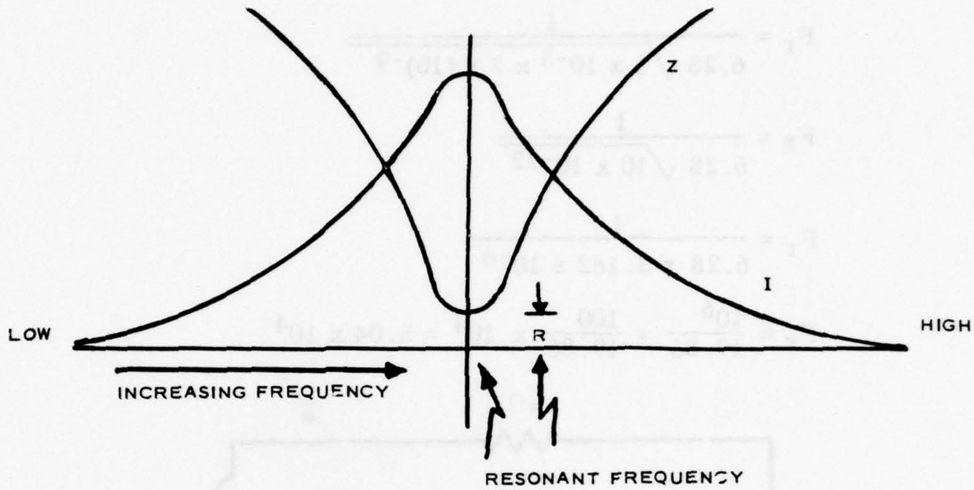

Diagram 90. Impedance curve of series circuit.

12. In practical resonant circuits, the resistance in the circuit has no effect on the resonant frequency; the resonant frequency is determined only by L and C.

13. In practical circuits, the reactances of L and C are not given; capacitances are given in microfarads (or micromicrofarads), and inductances are given in millihenries (or microhenries).

14. There is only <u>one</u> resonant frequency for one value of inductance in combination with one value of capacitance. The circuit shown in diagram 91 contains an inductor of 5 millihenries and a capacitor of 0.002 microfarad. The resonant frequency of the circuit may be determined as follows:

$$F_r = \frac{1}{2\pi\sqrt{LC}} \qquad (44)$$

F_r = Resonant frequency in cycles.

L = Inductance in henries.

C = Capacitance in farads.

$$F_r = \frac{1}{6.28\sqrt{0.005 \times 0.000000002}}$$

$$F_r = \frac{1}{6.28\sqrt{5 \times 10^{-3} \times 2 \times (10)^{-9}}}$$

$$F_r = \frac{1}{6.28\sqrt{10 \times 10^{-12}}}$$

$$F_r = \frac{1}{6.28 \times 3.162 \times 10^{-6}}$$

$$F_r = \frac{10^6}{19.86} = \frac{100}{19.86} \times 10^4 = 5.04 \times 10^4$$

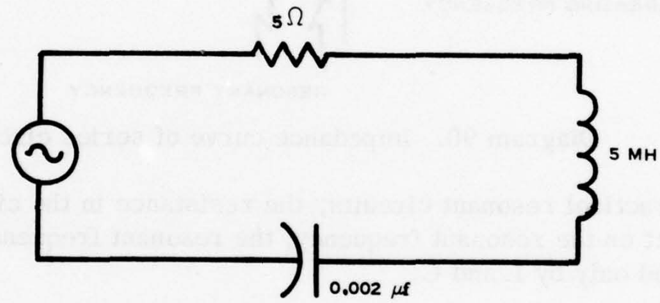

Diagram 91. Series circuit.

SUMMARY:

1. In a series circuit consisting of R, L, and C, the reactances of L and C tend to cancel one another.

2. A series circuit containing L and C is resonant when $X_L = X_C$.

3. There is only one resonant frequency for series circuits containing fixed values of L and C.

4. The resonant frequency of a series circuit consisting of L and C may be found by equation (44):

$$F_r = \frac{1}{2\ \pi\ LC}$$

F_r = Resonant frequency in cycles.

L = Inductance in henries.

C = Capacitance in farads.

5. When the frequency of the ac voltage applied to a series RLC circuit is lower than the resonant frequency of L and C, the impedance of the circuit is higher than the impedance at resonance, and consists of resistance and capacitive reactance in series. The line current leads the applied voltage. The circuit is said to be capacitive.

6. When the frequency of the ac voltage applied to a series RLC circuit is the same as the resonant frequency of L and C, the impedance of the circuit is minimum and is resistive (no reactance). The line current is in phase with the applied voltage.

7. When the frequency of the ac voltage applied to a series RLC circuit is higher than the resonant frequency of L and C, the impedance of the circuit is higher than the impedance at resonance and consists of resistance and inductive reactance in series. The line current lags the applied voltage. The circuit is said to be inductive.

LESSON PLAN

R, L, AND C IN PARALLEL

OBJECTIVE:

To explain and demonstrate:

1. The effects of inductance and capacitance when connected in parallel,
2. How the impedance of parallel circuits consisting of R, L, and C varies when the frequency of the ac generator is changed,
3. The characteristics of a parallel resonant circuit, and
4. How to determine the resonant frequency of any parallel LC combination.

INTRODUCTION:

Parallel resonant circuits are equally as important as series resonant circuits, but their effects are opposite to those of series resonant circuits. By means of combinations of both series resonant and parallel resonant circuits, it is possible to "guide" ac voltages into certain channels and block ac voltages from other channels. As an example, series and parallel resonant circuits are the electronic components that make it possible to tune a radio receiver to a single station and block the signals from other stations.

PRESENTATION:

1. The same equation (44) that was used for series LC circuits is used to determine the resonant frequency of a parallel LC combination.

$$F_r = \frac{1}{2\pi LC}$$

2. If an inductor, a capacitor, and a resistor are connected in parallel as shown in diagram 92, the impedance of the circuit may be calculated by finding the line current, then dividing the line voltage by the line current by equation (30):

$$Z = \frac{E_t}{I_t}.$$

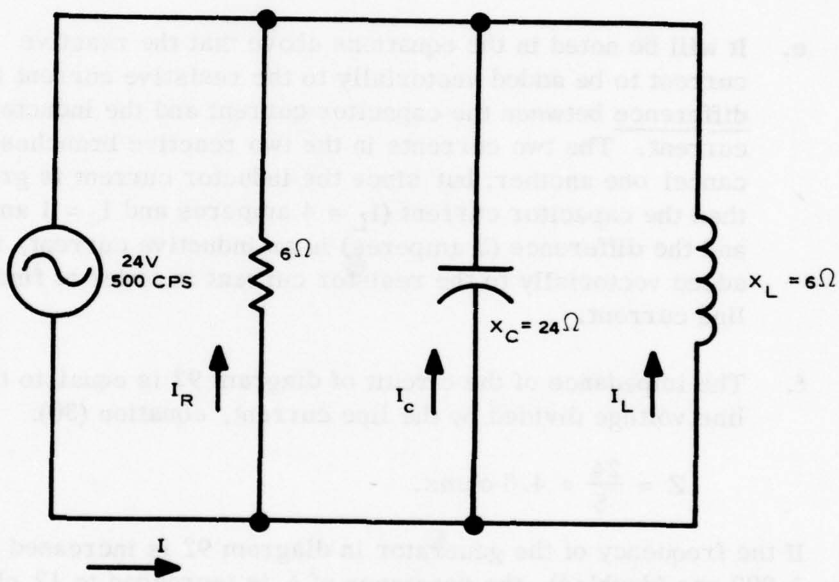

Diagram 92. Parallel RLC circuit.

a. The current through the six-ohm resistor is found by equation (1):

$$I_R = \frac{24}{6} = 4 \text{ amperes.}$$

b. The current through the capacitor is found by equation (38):

$$I_C = \frac{24}{24} = 1 \text{ ampere.}$$

c. The current through the inductor is found by equation (27):

$$I_L = \frac{24}{6} = 4 \text{ amperes}$$

d. The line current of the circuit is the vector sum of the currents of the three branches:

$$I = \sqrt{(I_R)^2 + (I_L - I_C)^2} \qquad (45)$$

$$= \sqrt{4^2 + (4-1)^2} = \sqrt{4^2 + 3^2}$$

$$= \sqrt{16 + 9} = \sqrt{25} = 5 \text{ amperes.}$$

e. It will be noted in the equations above that the reactive current to be added vectorially to the resistive current is the difference between the capacitor current and the inductor current. The two currents in the two reactive branches tend to cancel one another; but since the inductor current is greater than the capacitor current (I_L = 4 amperes and I_C = 1 ampere), and the difference (3 amperes) is an inductive current, it is added vectorially to the resistor current in order to find the line current.

f. The impedance of the circuit of diagram 92 is equal to the line voltage divided by the line current, equation (30):

$$Z = \frac{24}{5} = 4.8 \text{ ohms.}$$

3. If the frequency of the generator in diagram 92 is increased to 1,000 cps (doubled), the reactance of L is increased to 12 ohms (doubled), and the reactance of C is decreased to 12 ohms (halved). The results of the change in generator frequency appear in diagram 93.

4. Since $X_C = X_L$, the circuit of diagram 93 is a resonant circuit, and the impedance of the circuit is found in the same way that the impedance of the circuit of diagram 92 is found.

a. The resistor current is found by equation (1):

$$I_R = \frac{24}{6} = 4 \text{ amperes.}$$

b. The capacitor current is calculated by equation (38):

$$I_C = \frac{24}{12} = 2 \text{ amperes.}$$

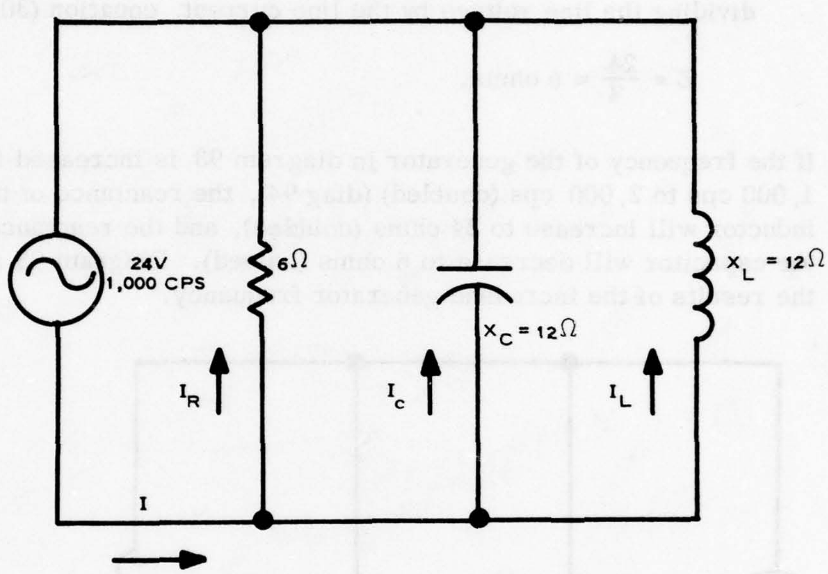

Diagram 93. Parallel resonant circuit.

c. The inductor current is determined by equation (27):

$$I_L = \frac{24}{12} = 2 \text{ amperes.}$$

d. Since the inductor current is equal to the capacitor current, the two currents will cancel one another completely, and the line current will consist only of the current through the resistor. This fact is apparent when solving for the line current by vector addition of the branch currents (equation (45)):

$$I = \sqrt{(I_R)^2 + (I_L - I_c)^2}$$

$$= \sqrt{4^2 + (2-2)^2} = \sqrt{4^2 + 0^2}$$

$$= \sqrt{4^2} = 4 \text{ amperes.}$$

e. The impedance of the circuit of diagram 93 is found by dividing the line voltage by the line current, equation (30):

$$Z = \frac{24}{4} = 6 \text{ ohms.}$$

5. If the frequency of the generator in diagram 93 is increased from 1,000 cps to 2,000 cps (doubled) (diag 94), the reactance of the inductor will increase to 24 ohms (doubled), and the reactance of the capacitor will decrease to 6 ohms (halved). Diagram 95 shows the results of the increased generator frequency.

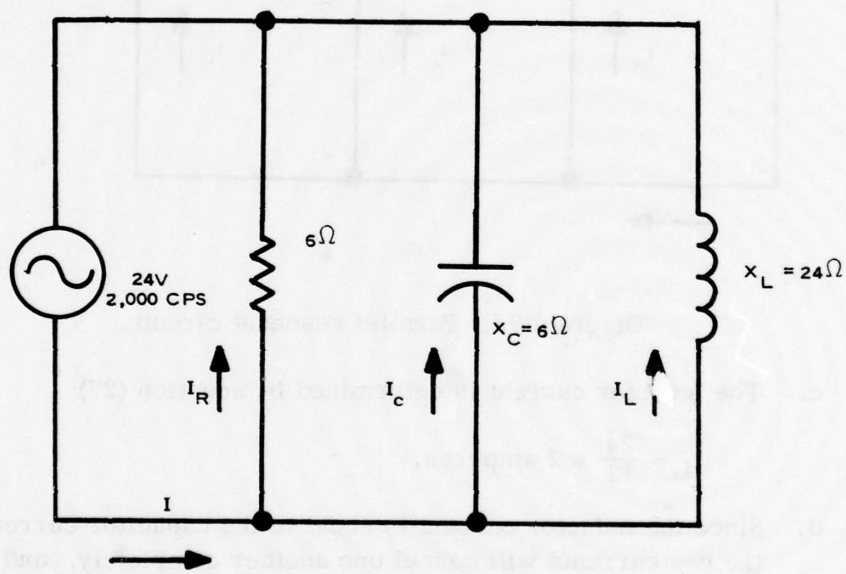

Diagram 94. Problems using R, L, and C in parallel.

a. The branch currents of the circuit of diagram 94 are found by equations (1), (38), and (27):

$$I_R = \frac{24}{6} = 4 \text{ amperes,}$$

$$I_C = \frac{24}{6} = 4 \text{ amperes, and}$$

$$I_L = \frac{24}{24} = 1 \text{ ampere.}$$

b. The line current is the vector sum of the branch currents by equation (45):

$$I = \sqrt{(I_R)^2 + (I_C - I_L)^2}$$

$$= \sqrt{4^2 \ (4-1)^2} = \sqrt{4^2 + 3^2}$$

$$= \sqrt{16 + 9} = \sqrt{25} = 5 \text{ amperes.}$$

c. The impedance of the circuit is found by equation (30):

$$Z = \frac{24}{5} = 4.8 \text{ ohms.}$$

6. A comparison of the circuits of diagrams 92, 93, and 94 shows that the impedance of the circuit in diagram 93 (resonant circuit) is higher than the impedances of the other two circuits. The comparison also shows that the line current is lower in the resonant circuit of diagram 93 than the line currents of the other two circuits. Diagram 95 shows how both current and impedance varie with the frequency in a parallel resonant circuit.

SUMMARY:

1. The resonant frequency of any parallel LC circuit is found by equation (44):

$$F_r = \frac{1}{2 \pi \sqrt{LC}}$$

2. The impedance of a parallel LC circuit is highest at the resonant frequency. The impedance at resonance is resistive (no reactance).

3. When the frequency of the voltage applied to a parallel LC circuit is lower than the resonant frequency, the impedance is lower than at resonance, and the circuit is inductive because the line current lags the line voltage.

4. When the frequency of the voltage applied to a parallel LC circuit is higher than the resonant frequency, the impedance of the circuit is lower than at resonance, and the circuit is capacitive because the line current leads the line voltage.

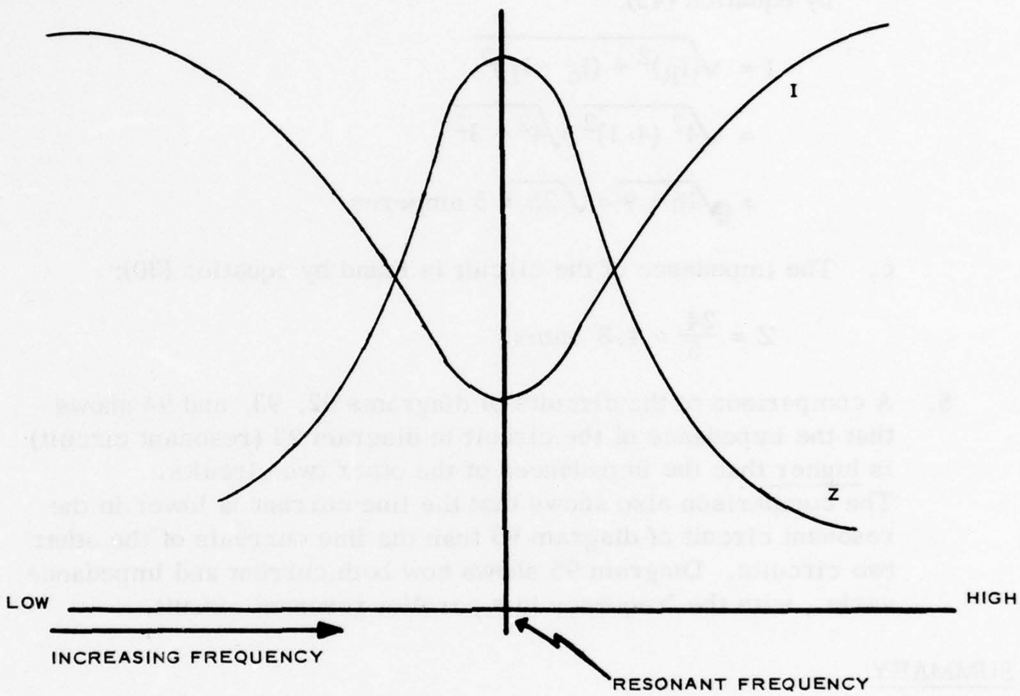

Diagram 95. I-Z curves for parallel resonant circuit.

5. In a parallel RLC circuit, the current in any branch is equal to the line voltage divided by the impedance of that branch.

6. In a parallel RLC circuit, the line current is equal to the vector sum of the branch currents by equation (45):

$$I = \sqrt{(I_R)^2 + (I_C - I_L)^2}.$$

7. In a parallel RLC circuit the inductive branch current and the capacitive branch current tend to cancel one another.

8. When an RLC parallel circuit is resonant, the inductive and capacitive branch currents cancel one another completely, and the line current consists only of the resistive branch current.

LESSON PLAN

TIME CONSTANTS

OBJECTIVE:

To explain and demonstrate:

1. The meaning of the term "time constant,"
2. The simple calculations used to determine the time constant of R and C in series and the time constant of R and L in series,
3. How to use the universal time-constant chart, and
4. The significance of time constants in electronic circuits.

> INSTRUCTOR'S NOTE: Make sure each student has a universal time-constant chart.

INTRODUCTION:

1. The charging or discharging of a capacitor through a resistor provides a simple means of controlling the variations of a voltage with respect to time. The control is necessary in many electronic circuits where a sawtoothed waveform must be produced, or a gating pulse must have a precise duration, or the pulse repetition frequency of a trigger pulse must be accurately controlled.

2. Though a comprehensive knowledge of time constants is not absolutely necessary to the average radar technician, a basic knowledge of, and the ability to perform, simple time-constant calculations will give the technician a better understanding of the functions of time constants in waveshaping circuits.

PRESENTATION:

1. The time constant of a capacitor connected in series with a resistor is the time required for the capacitor to charge, through the resistor, to 63 percent of the applied voltage.

2. The statement in paragraph 1 above may be illustrated by the circuit of diagram 96(1). It is assumed that the capacitor in the circuit has no charge before the switch is closed. The following statements describe the conditions in the circuit before and after the switch is closed.

   a. Before the switch is closed, there is no current flowing in the circuit, there is no charge on the capacitor, and there is no voltage drop across the resistor.

   b. When the switch is closed, the capacitor will charge to the applied voltage after a measurable period of time.

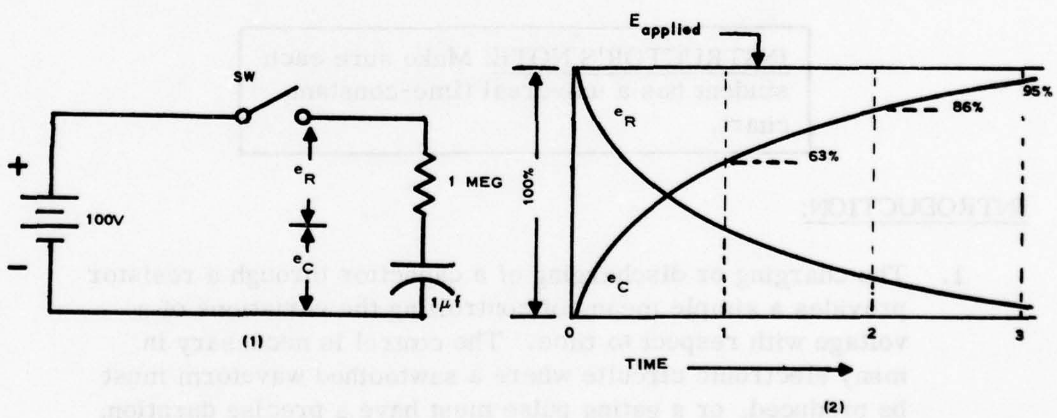

Diagram 96. Series RC circuit.

   c. Since the resistor in series with the capacitor limits the rate of flow of electrons, there is a delay in the rise of voltage across the capacitor. The delay in the rise of capacitor voltage is indicated by the rising curve in diagram 96(2).

d. The time of rise of capacitor voltage becomes longer as the capacitor is made larger, or the time of rise becomes longer if the resistor is increased in value to put a greater restriction on the flow of current (electrons).

e. The delay in the rise of e_C is proportional to the product of R and C. (The small "e" refers to instantaneous values of voltage.)

f. The product of R in ohms and C in farads is called the time constant.

$$TC = R \times C \tag{46}$$

g. The time constant of the circuit in diagram 96(1) is:

$$TC = RC = 1,000,000 \times 0.000001 = 1 \text{ second.}$$

h. At the instant the switch in diagram 96(1) is closed (time zero in the graph of diagram 96(2)), all of the applied voltage appears across the resistor.

i. The current that flows the instant the switch is closed may be found by Ohm's law equation (1):

$$I = \frac{100}{1,000,000} = 0.0001 \text{ ampere.}$$

j. As current flows in the circuit, the voltage across the capacitor rises because the current flow is charging the capacitor.

k. In one-tenth of a second (1/10 of a time constant), the voltage across the capacitor rises to 10 volts.

l. While the voltage across the capacitor is rising from 0 to 10 volts, the voltage across the resistor is decreasing from 100 volts to 90 volts. This phenomenon is explained by Kirchhoff's voltage law which states that the sum of the voltage drops in a circuit is always equal to the applied voltage. Therefore, while e_C is rising, e_R is falling; and at every instant, their sum is equal to the 100 volts applied.

m. Since the voltage across the resistor is decreasing, the current flow is decreasing (Ohm's law). The decreasing current flow causes the capacitor to charge at a lower rate. This accounts for the more gradual rise of e_C during the upper part of the curve (diag 96(2)).

n. At the end of 1 second (1 time constant in this example), the capacitor will have charged to 63 percent of the applied voltage (63 percent of 100 volts = 63 volts), and the voltage across the resistor will have decreased to 37 percent (37 volts) of the applied voltage (100 volts).

o. At the end of 2 seconds (2 time constants), e_C is 86 volts, and e_R is 14 volts.

p. At the end of 5 seconds (5 time constants), e_C is greater than 99 volts. Theoretically, the capacitor never charges to the applied voltage at the end of 5 time constants.

q. For practical applications, it may be assumed that at the end of 5 time constants e_R is zero and the current flow is zero.

3. The circuit of diagram 97 is arranged with a switch which will permit both charging and discharging of the capacitor through the 10,000-ohm resistor. The following statements apply to the circuit of diagram 97.

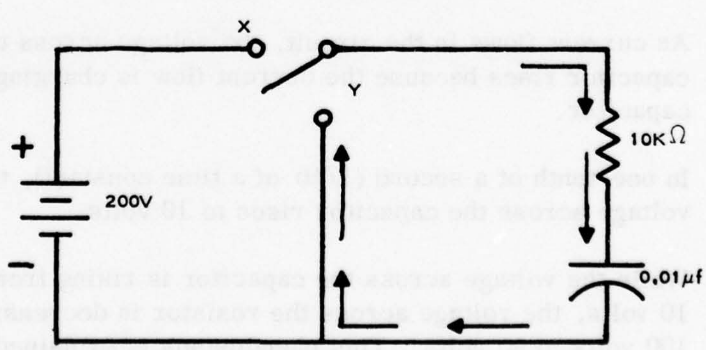

Diagram 97. Discharge of C.

a. When the arm of the switch in diagram 97 is moved to contact X, the battery will charge C through R. When the switch arm is moved to contact Y, the capacitor will discharge through the resistor. The direction of discharge current flow is indicated by the arrows.

b. The time constant of R and C is found by equation (46):

$$TC = RC = 10{,}000 \times 0.00000001$$

$$= 0.0001 \text{ second}$$

$$= \frac{100}{1{,}000{,}000} \text{ seconds}$$

$$= 100 \text{ microseconds.}$$

c. The arm of the switch is moved to contact X and allowed to remain there longer than 5 time constants (500 μsec) to permit C to charge to 200 volts.

d. Refer to the universal time-constant chart (curves shown in diag 98), and notice that the time between 0 and 1 on the chart represents a time of 100 microseconds for the circuit in diagram 97. For the circuit in diagram 97, the percentages of applied voltage on the chart refer to percentages of 200 volts.

e. At the instant the switch arm touches contact Y, the full charge of the capacitor (200 volts) appears across the resistor; and the current through the resistor, according to Ohm's law, equation (1), is:

$$I = \frac{200}{10{,}000} = 0.02 \text{ ampere.}$$

f. As current flows, the capacitor discharges, and the capacitor voltage decreases. As e_C decreases, e_R also decreases since e_R is the same as e_C. As e_R decreases, the current decreases; and since the current that flows is discharging C, the rate at which C discharges decreases. The gradual decrease of the

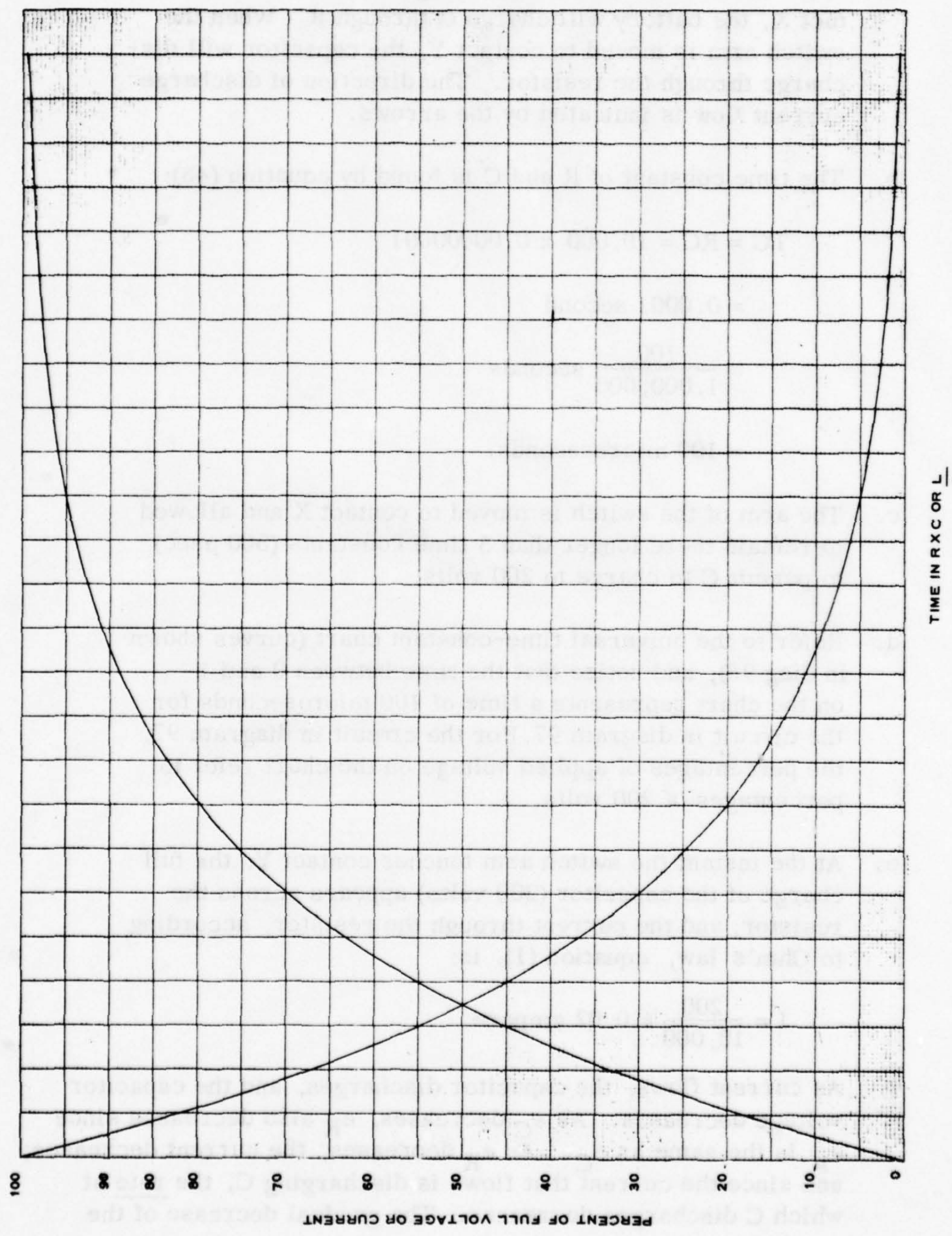

Diagram 98. Universal time-constant chart.

rate of fall of e_C is represented by the curve which falls from the upper left-hand corner of the time-constant chart (diag 98).

g. The falling curve on the time-constant chart represents three percentage values as time progresses from zero time. (Zero is the instant the switch arm touches contact Y.) The percentage values are:

1) The percentage of the initial voltage across R,

2) The percentage of the initial voltage across C, and

3) The percentage of the initial current through R.

4. The universal time-constant chart may be used to determine current or voltage at any instant of time after a capacitor starts to <u>charge</u>, or at any instant of time after a capacitor starts to <u>discharge</u>.

5. An example of the use of the time-constant chart is given below. The circuit of diagram 99 will be used for two problems.

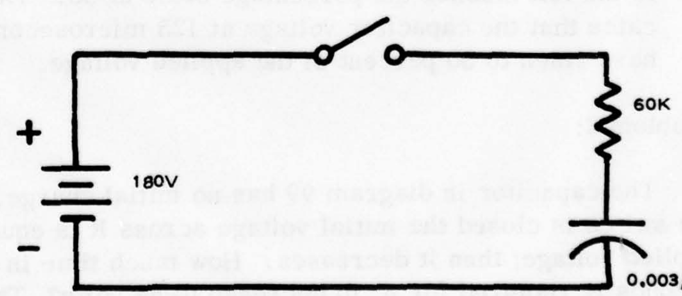

Diagram 99. Problems using the universal time-constant chart.

a. Problem 1:

The capacitor in the circuit of diagram 99 has no initial charge. What is the instantaneous voltage across

the capacitor 125 microseconds after the switch is closed? The solution is shown below.

1) The time constant of R and C:

$$TC = 60,000 \times 0.000000003,$$

$$= 6 \times 10^4 \times 3 \times 10^{-9} = 18 \times 10^{-5}, \text{ or}$$

$$= 180 \times 10^{-6} = 180 \text{ microseconds.}$$

2) Since the question asks for e_C at 125 microseconds, it is necessary to find what percentage 125 microseconds is of 180 microseconds.

$$\% \text{ of TC} = \frac{125}{180} \times 100 = 69.5\%$$

3) At the bottom of the chart, find the point which represents 0.695 of 1 time constant. Since e_C is the rising curve on the chart, the point (0.695) is projected upward vertically to the e_C curve. The point on the curve is projected horizontally to the left to the percentage scale. The projection to the left touches the percentage scale at 50. This indicates that the capacitor voltage at 125 microseconds will have risen to 50 percent of the applied voltage.

b. Problem 2:

The capacitor in diagram 99 has no initial charge. When the switch is closed the initial voltage across R is equal to the applied voltage; then it decreases. How much time in microseconds is required for e_R to decrease to 54 volts? The solution is shown as follows.

1) In problem 1, it was found that the time constant is 180 microseconds.

2) Find the percentage that 54 volts is of 180 volts.

$$\% \text{ of TC} = \frac{54}{180} \times 100 = 30\%$$

3) Refer to the time-constant chart (diag 98), and notice that the 30 percent point on the left vertical scale is projected horizontally to the right to the e_R curve (falling curve).

4) The point found on the e_R curve is projected vertically downward to the time-constant scale.

5) The point located on the time-constant scale is 1.2, indicating that 1.2 time constants are required for e_R to fall to 54 volts.

6) Since one time constant is 180 microseconds, 1.2 time constants are equal to 1.2 x 180 = 216 μsec.

7) The time required (after the switch is closed) for e_R to fall to 54 volts is 216 microseconds.

> <u>INSTRUCTOR'S NOTE</u>: Put a circuit similar to diagram 99 on the blackboard. Change the values of E, R, and C; and have student use the universal time-constant chart to find unknown values. Devise several problems for exercises if time permits.

6. The universal time-constant chart may be used in conjunction with the series RL circuit of diagram 100.

   a. The time constant for a series RL circuit may be found by the equation:

$$TC = \frac{L}{R}. \qquad (47)$$

   b. The time constant of the circuit in diagram 100 is found by equation (47):

$$TC = \frac{2}{50} = 0.04 \text{ second.}$$

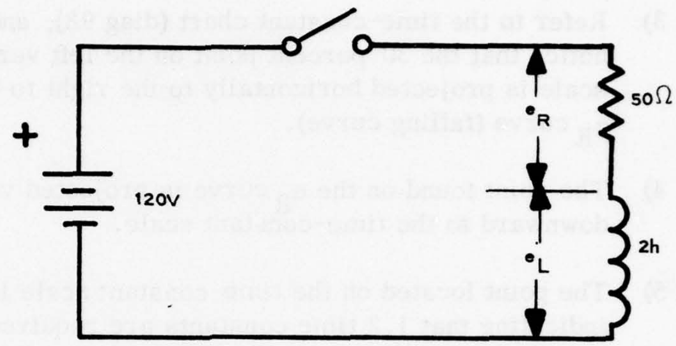

Diagram 100. Series RL circuit.

c. The instant the switch is closed (diag 100), the initial and progressive circuit conditions are as follows:

1) At the first instant, the entire applied voltage appears across L, but it decreases as time progresses. (See falling curve on the time-constant chart.)

2) At the first instant, the current is zero, but it rises as time progresses. (See rising curve on the time-constant chart.)

3) At the first instant, e_R is zero, but it rises as time progresses. (See rising curve on the time-constant chart.)

4) In a time equal to one time constant, e_L will fall to 37 percent of the initial voltage.

5) In a time equal to one time constant, e_R will rise to 63 percent of the applied voltage.

6) In a time equal to one time constant, I will increase to 63 percent of the maximum value.

7) The maximum value of current may be found by Ohm's law, equation (1).

7. The use of the time-constant chart in conjunction with a series RL circuit is illustrated by the problem below.

   a. Refer to the circuit of diagram 100. What is the instantaneous voltage across the inductor 0.024 second after the switch is closed? The solution is as follows.

      1) The time constant of the circuit is found by equation (47):

$$TC = \frac{L}{R} = \frac{2}{50} = 0.04 \text{ second.}$$

      2) What percentage of one time constant is the time of 0.024?

$$\% \text{ of } TC = \frac{0.024}{0.04} \times 100 = 60\%$$

      3) On the time-constant chart, it is found that at 60 percent of one time constant, the voltage across the inductor will fall to 55 percent of the initial voltage.

      4) The initial voltage across the inductor (e_L at instant the switch is closed) is 120 volts.

      5) 55% of 120 volts: $e_L = 0.55 \times 120 = 66$ volts.

      6) Answer: The voltage across the inductor 0.024 second after the switch is closed is 66 volts.

INSTRUCTOR'S NOTE: Put a circuit similar to diagram 100 on the blackboard. If time permits, devise several problems for students to solve by means of the universal time-constant chart.

SUMMARY:

1. The time constant of a circuit can be said to be the interval of time that it takes a capacitor to charge to 63 percent of the applied voltage through a given value of resistance, and by the same token, to discharge 37 percent of its voltage through a given resistance.

2. For all practical purposes, it is agreed that a capacitor is fully charged or discharged at the end of five time constants.

LESSON PLAN

TRANSFORMERS

OBJECTIVE:

To explain and demonstrate:

1. The common uses of transformers,

2. The relationship between voltage ratio and turns ratio in transformers,

3. The relationship between primary and secondary current in transformers, and

4. How transformers may be used as impedance-matching devices.

INTRODUCTION:

1. The transformer is essential to power distribution systems, telephone and telegraph systems, and to electronics. This comparatively simple device can increase or decrease the magnitude of alternating voltages, couple grounded devices to ungrounded ones, and match unlike impedances. Furthermore, it can do all of these things with a minimum loss of power.

2. A transformer is defined as a device for transferring electrical power from one circuit to another by means of a changing magnetic field.

PRESENTATION:

1. The basic power transformer consists of an iron core having two coil windings, as shown in diagram 101. The winding that is connected to the source of ac power is called the primary winding, and the winding which supplies power to the load is called the secondary winding.

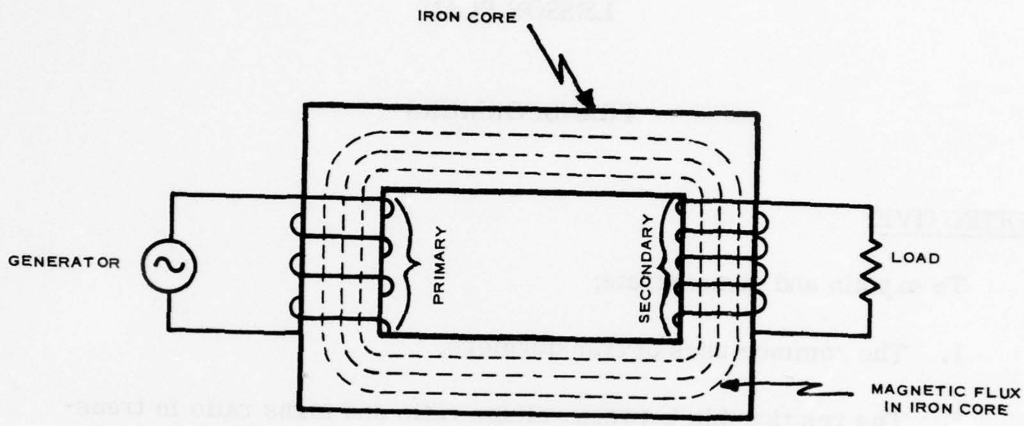

Diagram 101. Basic transformer.

2. If a transformer has a primary winding of 100 turns and a secondary winding of 50 turns, the voltage supplied to the load by the secondary winding is one-half of the voltage supplied to the primary winding by the generator. The foregoing statement is illustrated by the circuit in diagram 102.

3. If the primary winding of a transformer has more turns than the secondary, the transformer is a step-down transformer, and the primary voltage is higher than the secondary voltage. A step-up transformer has more turns on the secondary than on the primary, and the primary voltage is lower than the secondary voltage.

4. In a transformer, such as is illustrated in diagram 102, the ratio of primary turns to secondary turns is the same as the ratio of primary voltage to secondary voltage.

$$\frac{N_p}{N_s} = \frac{E_p}{E_s} \qquad (48)$$

N_p = number of primary turns.

N_s = number of secondary turns.

E_p = voltage applied to primary.

E_s = output voltage of secondary.

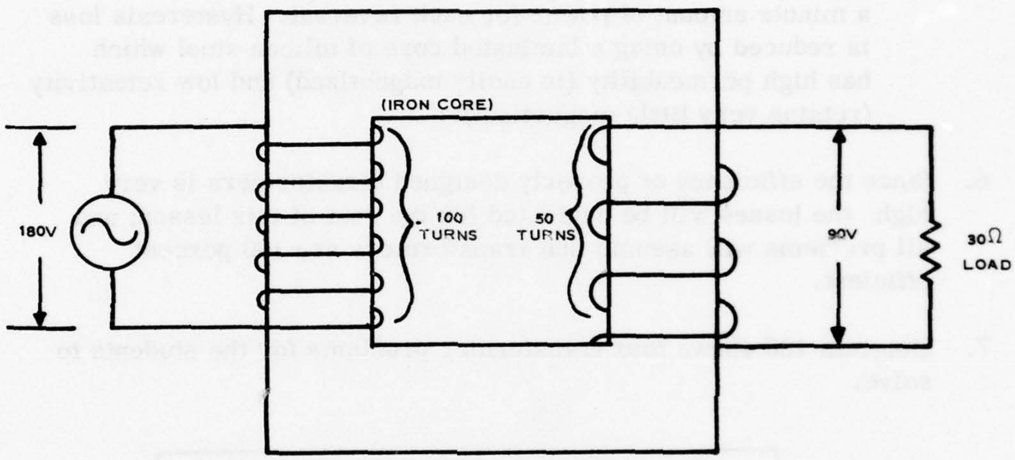

Diagram 102. Two-to-one step-down transformer.

5. Transformers are not 100 percent efficient, and the losses that occur result in heating of the iron core and the windings. The principal sources of loss are listed below.

   a. Losses equal to I^2R occur in all copper-wire windings which carry current. These losses are reduced by winding the coils with wire of the greatest practical diameter.

   b. Eddy-current losses occur in the iron core because the alternating magnetic flux will induce currents in the iron core as well as in the secondary winding. The iron core is a poor conductor, and the circulating currents in the core produce heat. Eddy-current losses are reduced by making

the core out of thin sheets of soft iron or steel. The laminations (thin sheets) are insulated from one another by a coating of nonconducting varnish.

c. Hysteresis losses occur in the molecules of the iron core. Since the magnetic flux is alternating, the continued reversal of the iron-molecule magnetic poles requires a minute amount of power for each reversal. Hysteresis loss is reduced by using a laminated core of silicon steel which has high permeability (is easily magnetized) and low retentivity (retains very little magnetism).

6. Since the efficiency of properly designed transformers is very high, the losses will be neglected for the rest of this lesson; and all problems will assume that transformers are 100 percent efficient.

7. Diagram 103 shows four transformer problems for the students to solve.

> INSTRUCTOR'S NOTE: Have students solve for required values in the problems of diagram 103, then use additional problems as time allows.

8. Assuming an efficiency of 100 percent, the power output of a transformer is the same as the input. Therefore, the product of primary voltage and primary current is equal to the product of secondary voltage and secondary current:

$$E_p I_p = E_s I_s. \qquad (49)$$

9. Diagram 104 shows a circuit in which 200 volts is applied to the primary of a four-to-one, step-down transformer. The secondary output is applied to a 12.5-ohm load. The following statements apply to the circuit of diagram 104.

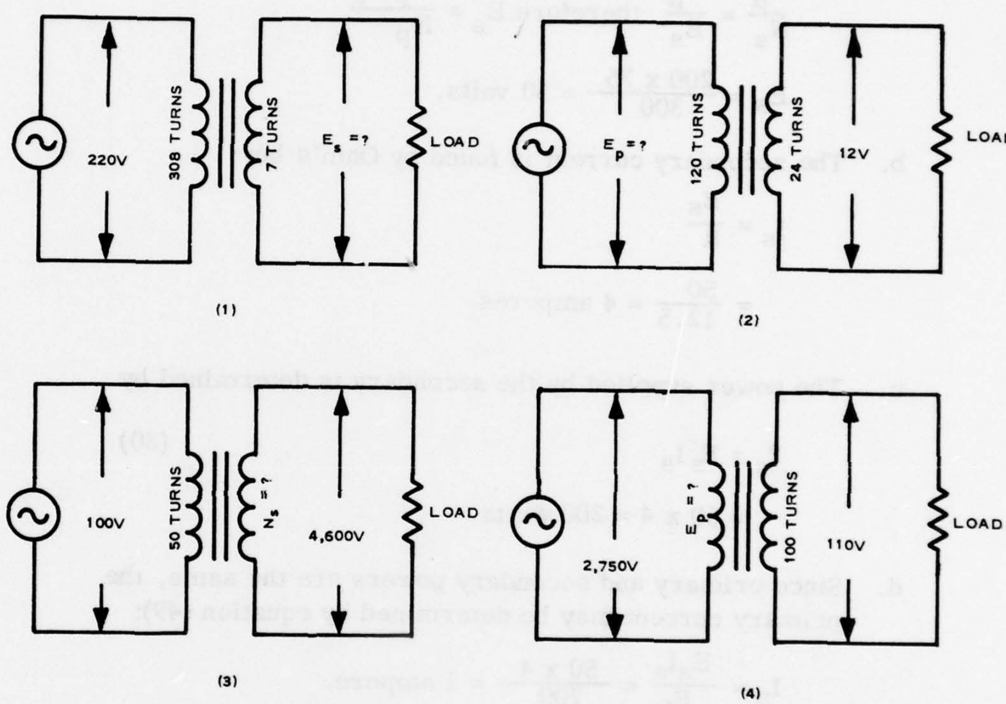

Diagram 103. Transformer problems.

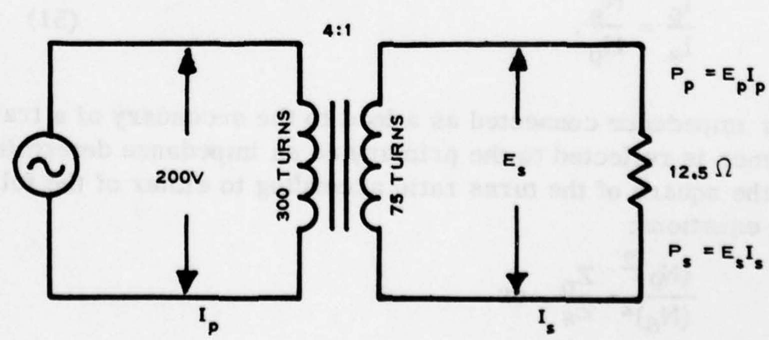

Diagram 104. Power illustration.

a. From the basic equation (48),

$$\frac{N_p}{N_s} = \frac{E_p}{E_s}, \text{ therefore } E_s = \frac{E_p N_s}{N_p}$$

$$E_s = \frac{200 \times 75}{300} = 50 \text{ volts.}$$

b. The secondary current is found by Ohm's law:

$$I_s = \frac{E_s}{R}$$

$$= \frac{50}{12.5} = 4 \text{ amperes}$$

c. The power supplied by the secondary is determined by

$$P_s = E_s I_s \tag{50}$$

$$= 50 \times 4 = 200 \text{ watts.}$$

d. Since primary and secondary powers are the same, the primary current may be determined by equation (49):

$$I_p = \frac{E_s I_s}{E_p} = \frac{50 \times 4}{200} = 1 \text{ ampere.}$$

10. The ratio of primary current to secondary current is the inverse of the ratio of primary turns to secondary turns:

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}. \tag{51}$$

11. Any impedance connected as a load to the secondary of a transformer is reflected to the primary as an impedance determined by the square of the turns ratio according to either of the following equations:

$$\frac{(N_p)^2}{(N_s)^2} = \frac{Z_p}{Z_s}, \text{ or}$$

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}. \tag{52}$$

12. Diagram 105 illustrates the impedance ratio given as equation (99). The following statements apply to the circuit of diagram 105(1).

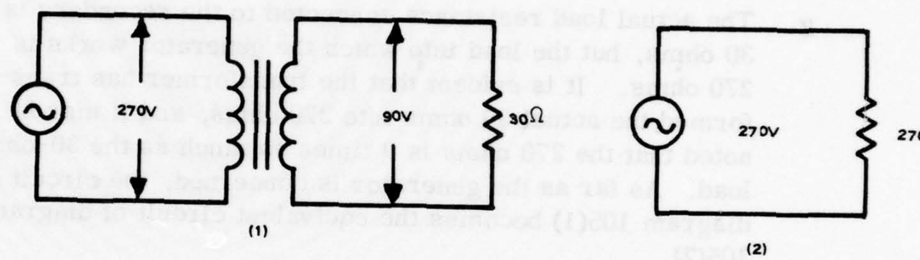

Diagram 105. Reflection of impedance.

a. The turns ratio of the transformer by equation (48) is:

$$\frac{N_p}{N_s} = \frac{E_p}{E_s} = \frac{270}{90} = \frac{3}{1} \text{ (3-to-1).}$$

b. The secondary current by Ohm's law, equation (24), is:

$$I_s = \frac{E_s}{Z_s}$$

$$= \frac{90}{30} = 3 \text{ amperes.}$$

c. The secondary power by equation (50) is:

$$P_s = 90 \times 3 = 270 \text{ watts.}$$

d. The primary power is 270 watts because primary and secondary powers are the same.

e. The primary current is:

$$I_p = \frac{P_p}{E_p} \qquad (53)$$

$$= \frac{270}{270} = 1 \text{ ampere.}$$

f. The impedance that the generator "sees" in the primary is determined by Ohm's law, equation (30):

$$Z_p = \frac{E_p}{I_p} = \frac{270}{1} = 270 \text{ ohms.}$$

g. The actual load resistance connected to the secondary is 30 ohms, but the load into which the generator works is 270 ohms. It is evident that the transformer has transformed the actual 30 ohms into 270 ohms, and it may be noted that the 270 ohms is 9 times as much as the 30-ohm load. As far as the generator is concerned, the circuit of diagram 105(1) becomes the equivalent circuit of diagram 105(2).

13. The exercise problems in diagram 106 are presented for solution by the students.

> INSTRUCTOR'S NOTE: Have students solve the problems in diagram 106 for required values, then put the solution on the blackboard. If time allows, have students solve for all other unknown values in each problem.

14. Impedance matching.

a. Transformers may be used for impedance matching to provide maximum transfer of power to a load. Impedance matching in electronics is necessary when the ac generator has an internal resistance that differs from the load resistance.

b. As an illustration of the effects of generator internal resistance, diagram 107 shows a generator having an internal resistance of 25 ohms. The internal resistance of the generator causes the output voltage to fall as the load passes more current.

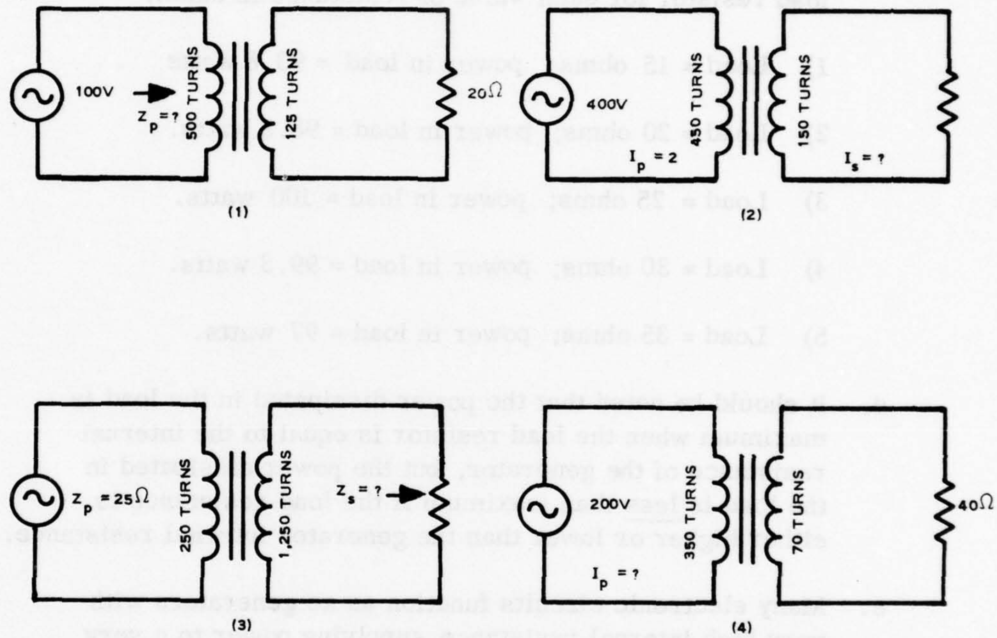

Diagram 106. Transformer problems.

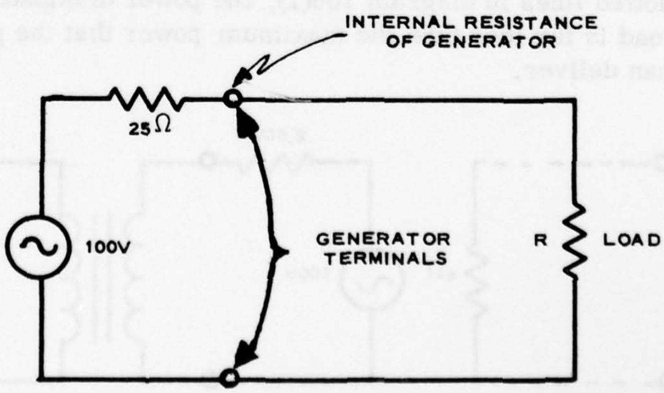

Diagram 107. Generator internal resistance.

c. If the load resistor in diagram 107 is varied from 15 ohms to 35 ohms in 5-ohm steps, the power delivered to the load varies. The list below shows the power dissipated in the load resistor for each value of resistance in ohms.

1) Load = 15 ohms; power in load = 93.8 watts

2) Load = 20 ohms; power in load = 98.5 watts.

3) Load = 25 ohms; power in load = 100 watts.

4) Load = 30 ohms; power in load = 99.3 watts.

5) Load = 35 ohms; power in load = 97 watts.

d. It should be noted that the power dissipated in the load is maximum when the load resistor is equal to the internal resistance of the generator, but the power dissipated in the load is less than maximum if the load resistance is either higher or lower than the generator internal resistance.

e. Many electronic circuits function as ac generators with very high internal resistance supplying power to a very low resistance load. Such a generator and load resistor is shown in diagram 108(1). If the four-ohm resistor is connected directly to the generator, as indicated by the dotted lines in diagram 108(1), the power dissipated in the load is far less than the maximum power that the generator can deliver.

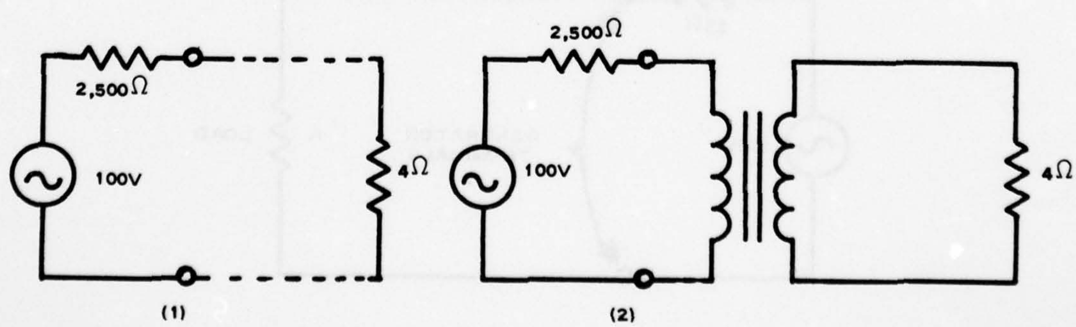

Diagram 108. Impedance-matching transformer.

f. The only load which would take the maximum power from the generator is one of 2,500 ohms, but the actual load is 4 ohms. To make the 4-ohm load appear to the generator as a 2,500-ohm resistance, it is necessary to use a transformer as shown in diagram 108(2).

g. The transformer shown in diagram 108(2) must reflect the 4-ohm resistor to the primary as 2,500 ohms. To calculate the correct turns ratio of the transformers, equation (52) is used:

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}} = \sqrt{\frac{2500}{4}} = \sqrt{625} = 25.$$

The transformer will be a 25-to-1, step-down transformer. At any one generator voltage, the maximum power will be delivered to the load.

INSTRUCTOR'S NOTE: Devise at least one additional problem involving matching transformers for students to solve.

15. Power transmission.

a. Both the high efficiency of transformers and the ease with which voltage levels may be changed make possible a great saving of power that otherwise might be lost when electrical energy must be transmitted over long distances.

b. Diagram 109(1) shows a generator connected to a motor load by very short connections. The efficiency of transmission of power from the generator is almost 100 percent because the voltage loss in the connecting wires is negligible.

c. If the motor in diagram 109(1) is at a distance of one mile from the generator, and if the connecting wires are No. 12 copper wire, the resistance of the transmission line causes excessive losses as shown in diagram 109(2). The efficiency

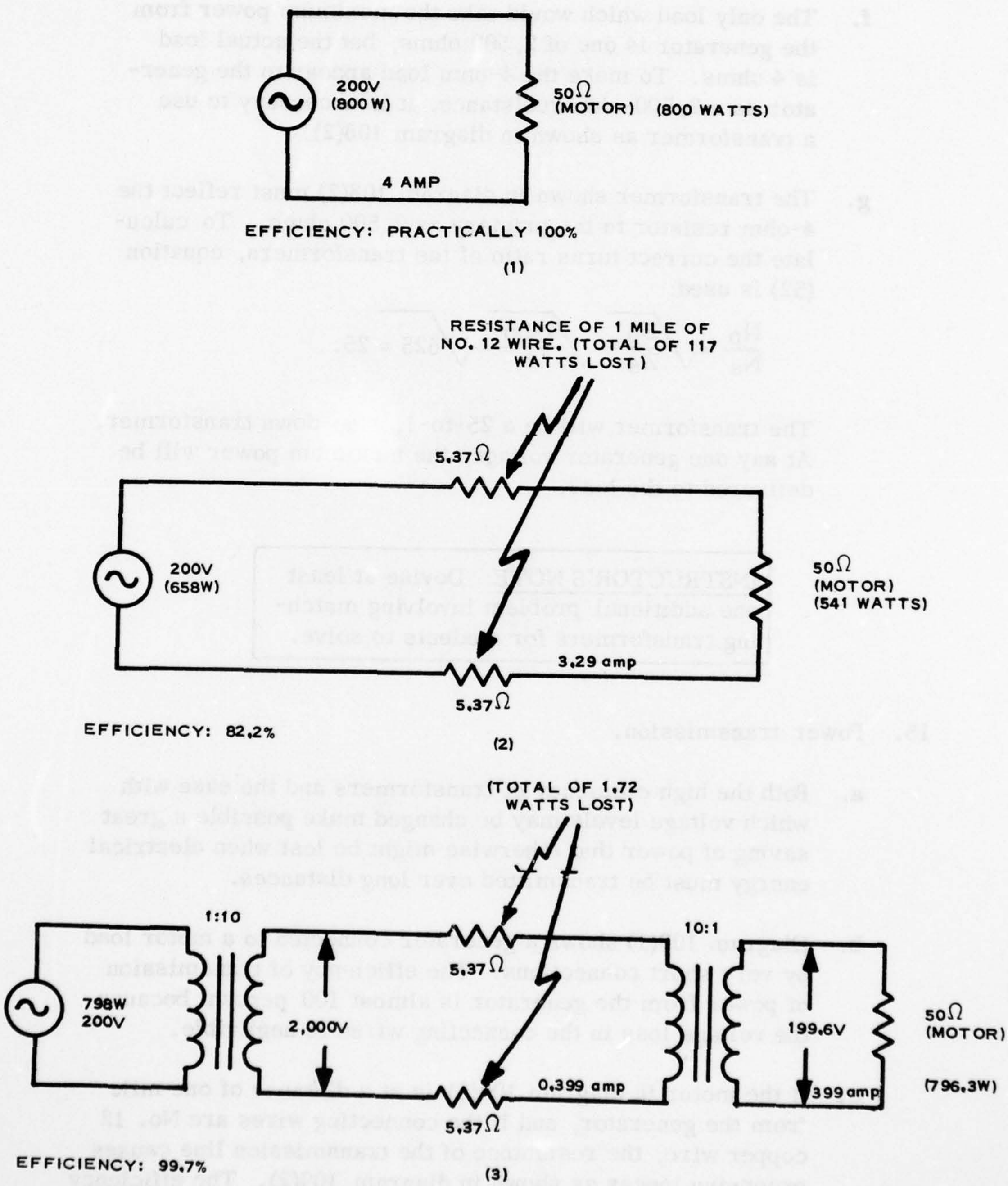

Diagram 109. Power transmission.

of the system is approximately 82 percent. This means that about 18 percent of the generated power is dissipated in heating the transmission line.

d. To improve the efficiency of the system, transformers are placed at the generator and at the motor as shown in diagram 109(3). The efficiency of this system would be over 99 percent if the transformer itself were 100 percent efficient. The losses in the line have been greatly reduced because the higher line voltage produces a much smaller current. Since there are small losses in the transformers, the efficiency in practical systems is not so high as indicated in diagram 109(3); but assuming transformer efficiencies to be 95 percent, the efficiency of the system shown would still be over 90 percent.

SUMMARY:

1. When two coils are placed in such an inductive relation to each other that the lines of force from one cut across the turns of the other, inducing a current, the combination can be called a transformer.

   a. The name is derived from the fact that energy is transferred or transformed from one winding to another.

   b. The inductance in which the original flux is produced is called the primary; the inductance which receives the induced current is called the secondary.

2. Transformers can have either air or magnetic cores depending on the frequencies at which they are to be operated. It should always be remembered that the transformer functions only if the primary voltage is changing or alternating.

LESSON PLAN

METERS

OBJECTIVE:

To explain and demonstrate:

1. The use of a voltmeter,
2. The precautions that must be observed when preparing to measure unknown voltages,
3. The use of an ammeter,
4. The use of an ohmmeter, and
5. The precautions that must be observed to obtain correct resistance measurements.

INTRODUCTION:

1. Electrical meters provide visual indications of electrical quantities. Since meters are sensitive and delicate, a great amount of damage to meters can occur through improper use.
2. This lesson is devoted to explanations of the use of meters and to the proper precautions to observe when using them.

PRESENTATION:

1. Voltmeters.
   a. Voltmeters are designed to measure electrical pressure (electromotive force) by measuring a very small current which is proportional to the voltage.

   b. A voltmeter is always connected between two points in a

circuit and measures the voltage difference between the two points. Diagram 110 shows a dc circuit with voltmeters placed at various positions to indicate the voltage differences between the points to which the voltmeter is connected. The following statements apply to the use of dc voltmeters as shown in diagram 110.

1) DC voltmeters are polarized; that is, the terminals or test leads are marked minus (-) or plus (+), and the positive lead is always connected to the part of the circuit nearest to the positive terminal of the dc source. The negative lead is connected to the part of the circuit nearest to the negative terminal of the source.

2) The voltmeter V1 in diagram 110 will indicate the voltage between the points W and Z, which is the power supply voltage.

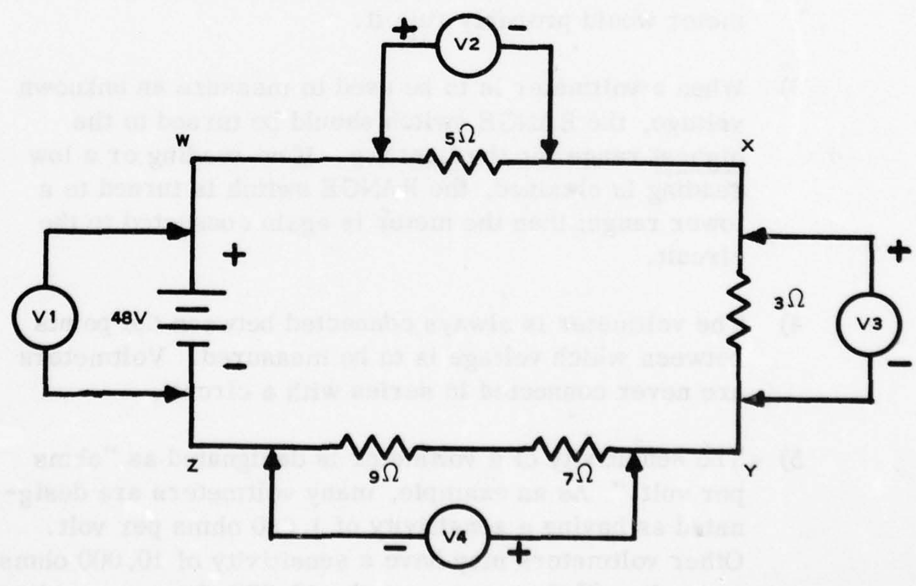

Diagram 110. DC voltage measurements.

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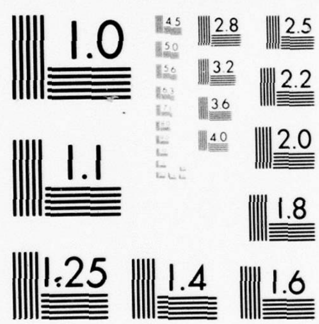

MICROCOPY RESOLUTION TEST CHART

3) The voltmeter marked V2 measures the voltage drop across the five-ohm resistor. The arrows on the connections to the meters indicate that test leads are used.

4) The voltmeter marked V4 indicates the total voltage drop across the nine-ohm and seven-ohm resistors.

c. The following statements apply to dc voltmeters in general.

1) A voltmeter has a very high internal resistance to limit the current flowing through the meter.

2) The range of a voltmeter indicates the maximum voltage to which the meter may be connected without damage. For example, a 100v voltmeter may be connected to any voltage between 0 and 100 volts. It would not be used in an attempt to read a voltage of 400 volts because the excessive current through the meter would probably ruin it.

3) When a voltmeter is to be used to measure an unknown voltage, the RANGE switch should be turned to the highest range for the first try. If no reading or a low reading is obtained, the RANGE switch is turned to a lower range; then the meter is again connected to the circuit.

4) The voltmeter is always connected between the points between which voltage is to be measured. Voltmeters are never connected in series with a circuit.

5) The sensitivity of a voltmeter is designated as "ohms per volt." As an example, many voltmeters are designated as having a sensitivity of 1,000 ohms per volt. Other voltmeters may have a sensitivity of 10,000 ohms per volt. Of the two types, the 10,000 ohms-per-volt voltmeter is the most sensitive, as it requires only one-tenth as much current to cause the meter to produce full-scale deflection.

6) The higher the sensitivity, the less effect the meter will have on the true voltage of the circuit being tested.

INSTRUCTOR'S NOTE: Explain by means of diagrams on the blackboard how a voltmeter may show an erroneous reading.

7) The positive (+) side of the voltmeter should always be connected to the positive side of the voltage to be measured.

2. Ammeters.

a. Ammeters (milliammeters or microammeters) must always be connected in series with the circuit in which current is to be measured. As an example, if it is desired to measure the current at point X of the circuit in diagram 111(1), the circuit must be opened and the ammeter inserted so that the ammeter becomes a part of the circuit as in diagram 111(2).

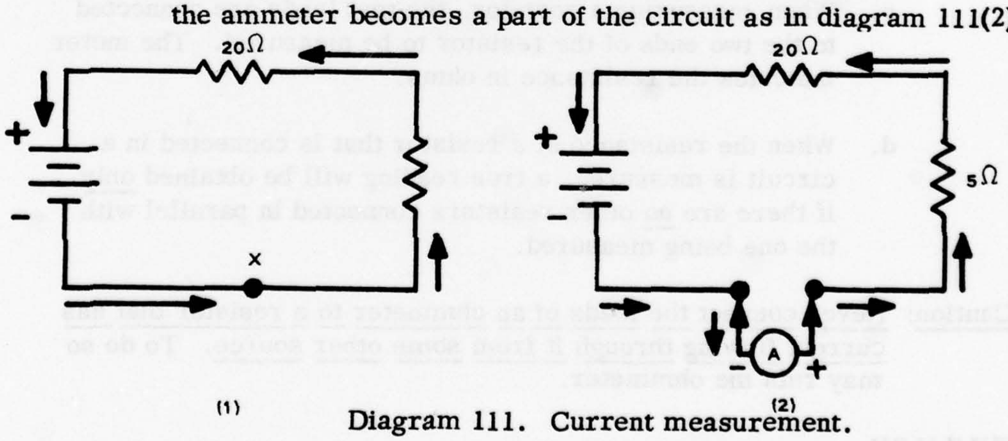

Diagram 111. Current measurement.

b. When measuring unknown currents, the ammeter RANGE switch must be switched to the highest range first; then, if necessary, the RANGE switch is moved to a lower range to get a more accurate reading, but never move the RANGE switch while current is flowing through the meter. To do so may ruin the meter.

c. Ammeters are polarized, and the terminal marked plus (+) must be connected to that part of the circuit which goes to the positive side of the power source.

d. All rules and precautions that apply to dc voltmeters and ammeters apply to ac voltmeters and ammeters with one exception: ac voltmeters and ammeters are not polarized, and it makes no difference which way the ac meter is connected to, or in, the circuit.

Caution: Never place an ammeter across the power source.

3. Ohmmeters.

a. An ohmmeter indicates the resistance of a resistor directly in ohms.

b. The essential parts of an ohmmeter are a low-range voltmeter, a small battery, and a pair of test leads.

c. When measuring a resistor, the test leads are connected to the two ends of the resistor to be measured. The meter indicates the resistance in ohms.

d. When the resistance of a resistor that is connected in a circuit is measured, a true reading will be obtained only if there are no other resistors connected in parallel with the one being measured.

Caution: Never connect the leads of an ohmmeter to a resistor that has current flowing through it from some other source. To do so may ruin the ohmmeter.

SUMMARY:

1. Voltmeters are always connected in parallel with the unknown voltage and great caution should be exerted in their use while measuring unknown voltage. Always use the high scales at the beginning.

2. Ammeters are always connected in series with the current being measured. The same precautions taken with voltmeters should be applied to ammeters.

LESSON PLAN

DIODES

OBJECTIVE:

To explain and demonstrate:

1. The characteristics of a vacuum-tube diode,

2. The conditions in a diode necessary for conduction or nonconduction, and

3. The characteristics of selenium, germanium, and silicon diodes.

INTRODUCTION:

1. The vacuum-tube diode was the first true radio vacuum tube; and, although vacuum tube applications have advanced tremendously in the last few decades, the simple diode is an indispensable part of the most complex radio and radar circuits. The simplicity of construction and operation of the diode in no way detracts from its importance, and there is no universal substitute for the diode.

2. Metallic diodes (often referred to as metallic rectifiers) have certain advantages, as compared to vacuum-tube diodes, for certain applications to be discussed later in this lesson. Metallic diodes produce less heat than vacuum-tube diodes, but they cannot operate as efficiently at high voltages as can vacuum-tube diodes.

PRESENTATION:

1. If a tungsten wire is heated in an evacuated glass bulb by means of an electric current (diag 112), electrons leave the surface of the heated tungsten filament. The filament must be heated to a rather high temperature (2,500° centigrade) before electron emission from the surface occurs. The heated molecules of the metal

vibrate very rapidly at high temperatures, and a few electrons attain enough velocity to escape from the surface of the metal (electrons cannot normally escape from a cold metallic surface). These free electrons form a cloud around the heated filament (diag 112).

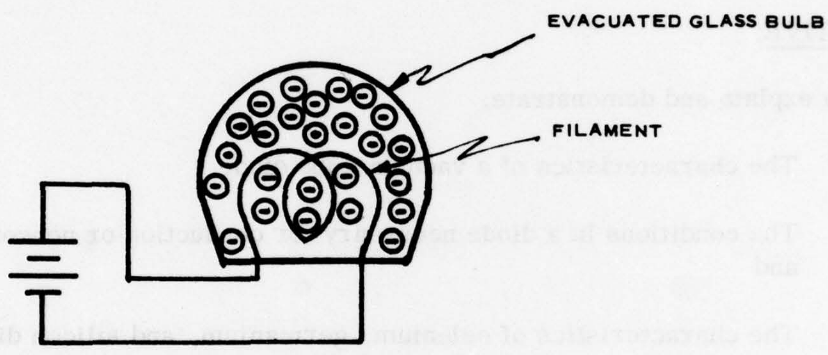

Diagram 112. Electron emission from heated filament.

> INSTRUCTOR'S NOTE: Use the vacuum-tube demonstrator to demonstrate diode construction.

2. If a separate, unheated electrode with a large surface is sealed in the evacuated glass enevelope, close to but not touching the filament, some of the electrons emitted by the filament will strike the cold electrode. The electrons striking the cold electrode (usually called the plate) become surface-bound and cannot leave the electrode.

3. Diagram 113 shows the two elements, filament and plate.

4. If a battery is connected in series with a milliammeter between one of the filament leads and the plate connection, a current will flow, provided that the plate in the diode is held positive with respect to the filament; and its amplitude may be read on the milliammeter. If the plate is held negative with respect to the filament, no current will flow.

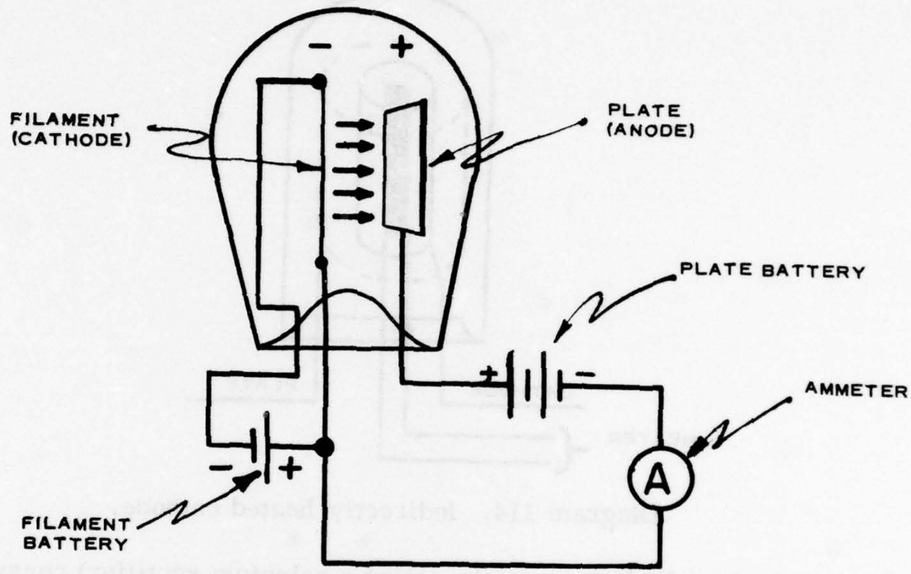

Diagram 113. Simple diode.

5. If the positive voltage on the plate of a diode is gradually increased, the electron flow from filament to plate will increase; but at some higher positive voltage the current will cease to increase, and a further increase in plate voltage will not cause an increase of electron flow. This condition is called cathode saturation (the filament is the cathode) and occurs when the plate is attracting all of the electrons emitted by the cathode. A further increase of electron flow is possible only by increasing the temperature of the filament in order to cause more electrons to be emitted from the surface.

6. In most diodes used at the present time, the filament is not the cathode but serves the purpose of heating a small cylindrical cathode that surrounds but is insulated from the heater (filament). The cylindrical cathode is coated on the outside with an oxide coating that is a very efficient emitter of electrons at a relatively low temperature (diag 114).

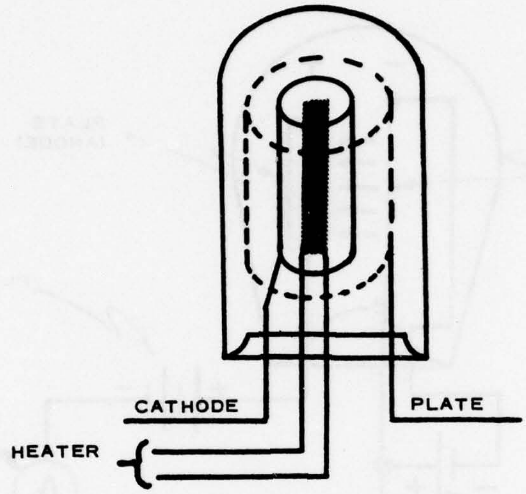

Diagram 114. Indirectly heated cathode.

7. A selenium diode (commonly called a selenium rectifier) consists of a thin coating of selenium on an iron disk, with another coating of a metal alloy over the selenium. Between the selenium and the alloy is a barrier layer which permits electrons to flow freely from the alloy to the selenium; but when the electrons attempt to flow from the selenium to the alloy, this layer offers a very high resistance.

   a. The symbol for a selenium diode is shown in diagram 115. The direction of the low resistance is the direction of the arrowhead in the symbol.

   b. Selenium diodes are used for rectification of low-frequency, alternating currents of relatively high amperage.

8. Germanium and silicon diodes function in the same way. The base (a very small slab of germanium or silicon) has a sharp-pointed bronze wire touching the surface (diag 116), and the low-resistance direction of current flow is from the base to the bronze wire.

   a. The symbol for germanium or silicon diodes is the same as that shown in diagram 115.

   b. Germanium or silicon diodes are used for rectification of very high-frequency, alternating currents of very low amplitude.

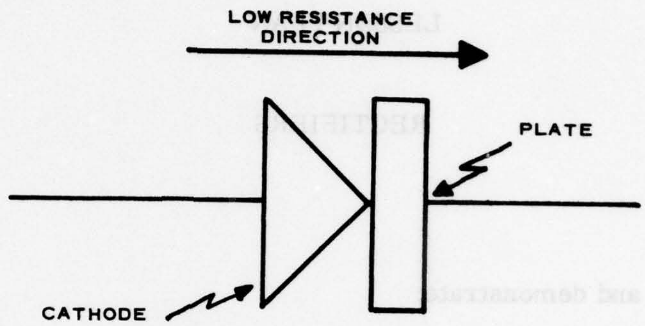

Diagram 115. Selenium diode.

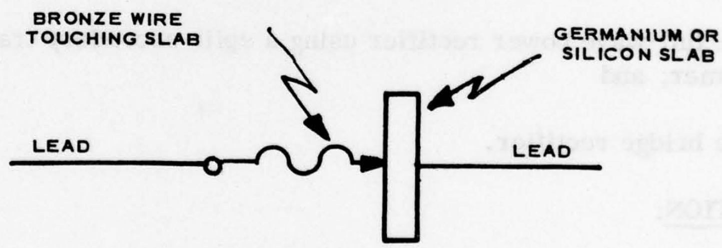

Diagram 116. Germanium or silicon diode.

SUMMARY:

1. **If a cathode, capable of being heated either indirectly or directly, is placed in an evacuated envelope along with a plate, the combination is called a diode.**

2. **The diode is the simplest of all vacuum tubes and is the fundamental type from which all others are derived.**

LESSON PLAN

RECTIFIERS

OBJECTIVE:

To explain and demonstrate:

1. The practical uses of diodes as rectifiers,

2. The simple, half-wave, rectifier circuit and the practical application of half-wave power rectifiers,

3. The full-wave power rectifier using a split-secondary transformer, and

4. The bridge rectifier.

INTRODUCTION:

1. A rectifier is a circuit which converts an alternating current to direct current.

2. Practically all vacuum-tube amplifiers require constant dc voltages from a power supply, but most commercial sources of electrical power provide alternating voltages only. Most radio receivers, transmitters, and radar sets therefore utilize rectifiers to convert commercial ac voltage to dc voltage.

3. Detectors, which are used in all radio receivers, function in exactly the same way as a power rectifier, although detectors normally rectify ac voltages of extremely high frequencies (radio frequencies) and relatively low amplitudes. Very small vacuum-tube diodes, or even germanium and silicon diodes, are normally used as detectors.

PRESENTATION:

1. Diodes are relatively good conductors when the plate is positive with respect to the cathode, but the resistance between cathode and plate becomes infinitely high when the plate is negative with respect to the cathode.

2. Transformers are normally used between the ac power line and the rectifier to provide isolation between the dc circuit and the power line. The use of transformers also makes it possible to provide any dc voltage that may be required by adjustment of the turns ratio of the transformers. For these reasons, all rectifier circuits to follow will show a transformer as the source of ac power.

3. In diagram 117, an ac voltage is applied to a load resistor, R. The voltage applied to the resistor is alternating in character; and thus the current flow through R is alternating. The voltage waveform in diagram 117(2) is that which appears at point X with respect to ground.

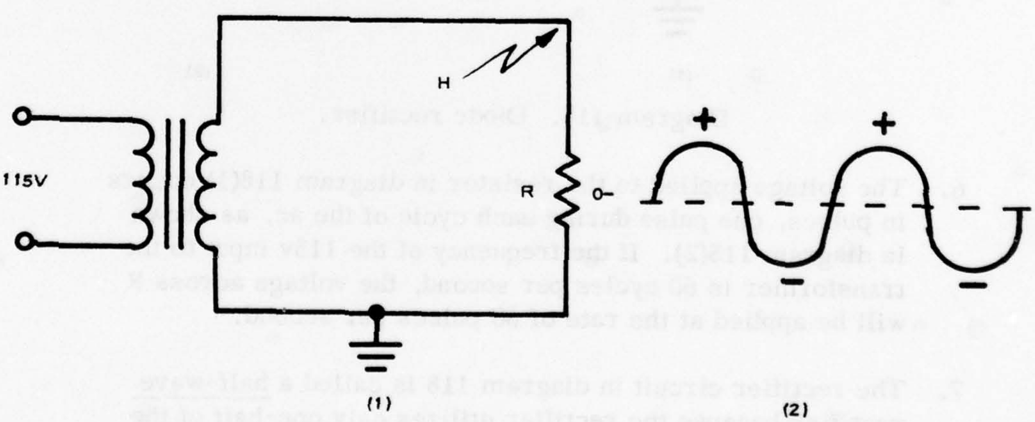

Diagram 117. AC circuit.

4. If it were possible to open the circuit by means of a switch during each negative half-cycle, the voltage applied to the resistor would consist of positive pulses of voltage only, and the current, even though it would be pulsating in character, would be moving in only one direction

5. A mechanical switch in the circuit of diagram 117(1) would be impractical; but if a diode is made part of the circuit, as shown in diagram 118(1) (the heater circuit for the diode has been omitted to simplify the drawing), the diode permits voltage to be applied to the load resistor during the positive half-cycle of the ac input but blocks the voltage during the negative half-cycles.

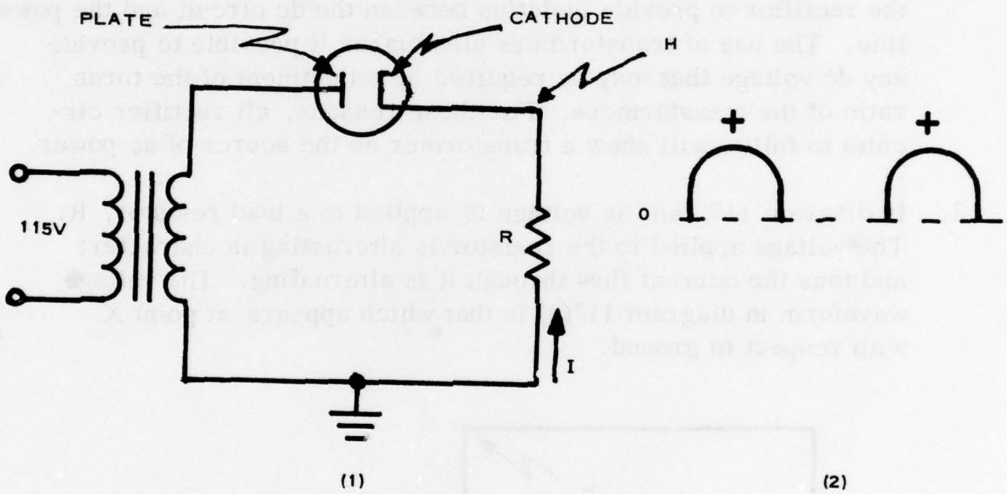

Diagram 118. Diode rectifier.

6. The voltage applied to the resistor in diagram 118(1) occurs in pulses, one pulse during each cycle of the ac, as shown in diagram 118(2). If the frequency of the 115v input to the transformer is 60 cycles per second, the voltage across R will be applied at the rate of 60 pulses per second.

7. The rectifier circuit in diagram 118 is called a <u>half-wave</u> rectifier because the rectifier utilizes only one-half of the ac cycle to produce a voltage across the load resistor, R.

8. The output voltage of the half-wave rectifier is seldom satisfactory as a dc power supply for vacuum-tube amplifiers because the amplifiers require a more constant dc voltage. To remove the pulsations, such as those shown in diagram 118(2), a filter must be used. Filters will be discussed in the next lesson.

9. Half-wave rectifiers are used principally for loads that require a constant and relatively small dc current.

10. A rectifier that utilizes both halves of the ac cycle in producing the pulsating dc output is called a full-wave rectifier.

11. Diagram 119(1) is the circuit of a full-wave rectifier.

    a. The transformer has two secondaries, one to produce five volts for heating the filament of the diode and the other to supply the high voltage to be rectified by the diode. The center tap of the high-voltage secondary is grounded.

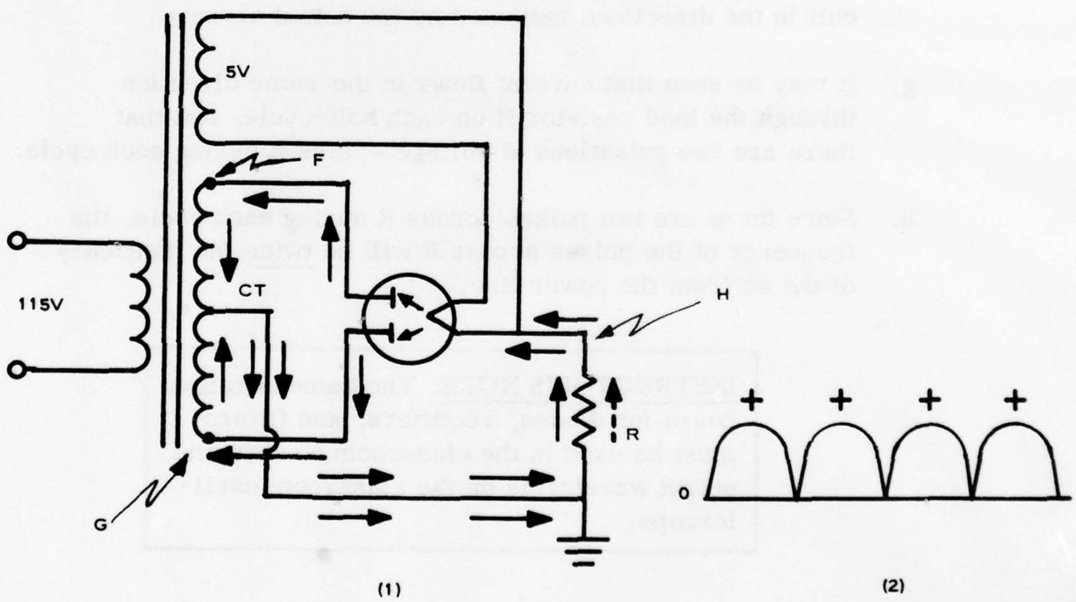

Diagram 119. Full-wave rectifier.

    b. The rectifier has two plates insulated from one another in a single glass envelope. The cathode is common to both plates. The filament also serves as the cathode in this tube. When either plate is positive with respect to the filament, electrons will flow from the filament to the positive plate.

c. The center tap of the high-voltage secondary is grounded and is a reference point (ground) from which all voltages are measured.

d. When point X on the high-voltage secondary is positive with respect to the center tap, point Y is negative with respect to the center tap. The voltages mentioned above occur on one-half of the ac cycle. On the other half-cycle, the voltages at points X and Y are reversed.

e. When point X is positive, current flows through the circuit as indicated by the solid arrows.

f. When point Y is positive, current will flow through the circuit in the directions indicated by the dotted arrows.

g. It may be seen that current flows in the same direction through the load resistor R on each half-cycle, and that there are two pulsations of voltage across R during each cycle.

h. Since there are two pulses across R during each cycle, the frequency of the pulses across R will be <u>twice</u> the frequency of the ac from the power line.

> <u>INSTRUCTOR'S NOTE</u>: The demonstration board for diodes, rectifiers, and filters must be used in the classroom to show the output waveforms on the classroom oscilloscope.

i. The higher frequency of the pulsating output of the full-wave rectifier makes it possible for the filter (to be discussed in the next lesson) to produce a more constant dc output.

j. The pulsations in the dc output of a rectifier are called <u>ripples</u>, and the number of pulsations per second is called the <u>ripple frequency</u>. The ripple frequency of the output of a half-wave rectifier is the same frequency as the ac input; the ripple frequency of the output of a full-wave rectifier is twice the frequency of the ac input.

k. Full-wave rectifiers are most efficient and can supply a greater output current than half-wave rectifiers. Full-wave rectifiers also have better voltage regulation and, therefore, are better suited for loads that may be variable.

12. Bridge rectifiers are another form of full-wave rectifier, but in this case the transformers need no center tap. Vacuum-tube diodes may be used in bridge rectifiers; but, when used, two filament transformers are needed.

13. Selenium rectifiers are most frequently used in bridge-rectifier circuits; therefore, the statements to follow will refer to this circuit in diagram 120.

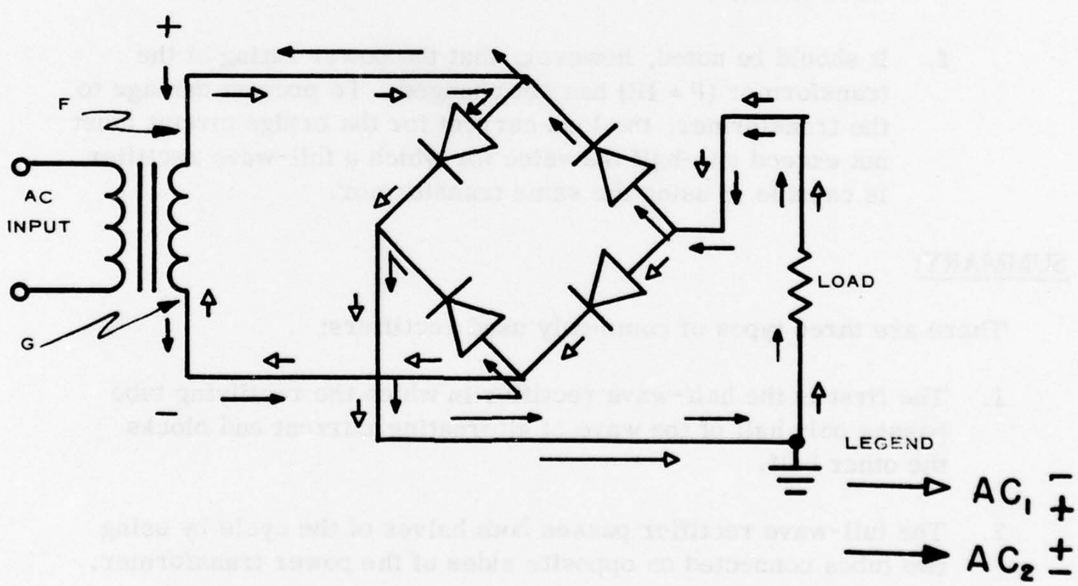

Diagram 120. Bridge rectifier using a selenium rectifier.

a. During one-half of the ac cycle, point X in diagram 120 is positive with respect to point Y, and the current flows through the circuit and the load resistor in the direction of the solid arrows. During the next half-cycle, point X is negative with respect to Y, and the current flows through the circuit and the load resistor in the direction of the dotted arrows.

b. In diagram 120, the current flow through the load resistor is in the same direction during each half-cycle. The voltage appearing across the load resistor is similar to the voltage shown in diagram 119(2).

c. When comparing full-wave and bridge rectifiers, one may say that, for the same transformer, the bridge rectifier will have twice the output voltage of the normal full-wave rectifier.

d. Since the full-wave bridge uses no center tap on the transformer secondary, the total secondary voltage appears across the bridge.

e. The bridge-output voltage is, therefore, twice that of a full-wave rectifier.

f. It should be noted, however, that the power rating of the transformer (P = IE) has not changed. To prevent damage to the transformer, the load current for the bridge circuit must not exceed one-half the value for which a full-wave rectifier is capable of using the same transformer.

SUMMARY:

There are three types of commonly used rectifiers:

1. The first is the half-wave rectifier in which the rectifying tube passes only half of the wave of alternating current and blocks the other half.

2. The full-wave rectifier passes both halves of the cycle by using two tubes connected on opposite sides of the power transformer.

3. The bridge rectifier is a full-wave rectifier in which four rectifying tubes are operated from a single, high-voltage secondary.

LESSON PLAN

FILTERS

OBJECTIVE:

To explain and demonstrate:

1. The operation of filters designed to remove the ripple from the dc output of a rectifier, and

2. The relative merits of several types of filters.

INTRODUCTION:

Most electronic circuits require a pure (unvarying) dc voltage as a power source. When the original source of power is ac, a rectifier must be used to produce the dc. Though the output of a rectifier is dc with great fluctuations (ripple) of the voltage, a filter connected between the rectifier and the load will reduce the fluctuations to such an extent that the dc may be considered pure.

PRESENTATION:

1. Diagram 121(1) is a half-wave rectifier with a capacitor in parallel with the load.

> INSTRUCTOR'S NOTE: Use the diode-rectifier filter demonstration board to illustrate all waveforms given in this lesson.

a. If the capacitor C were not present, the voltage across the load would consist of a series of pulses separated by periods of time between the pulses when no voltage would be reaching the load (pulsating dc).

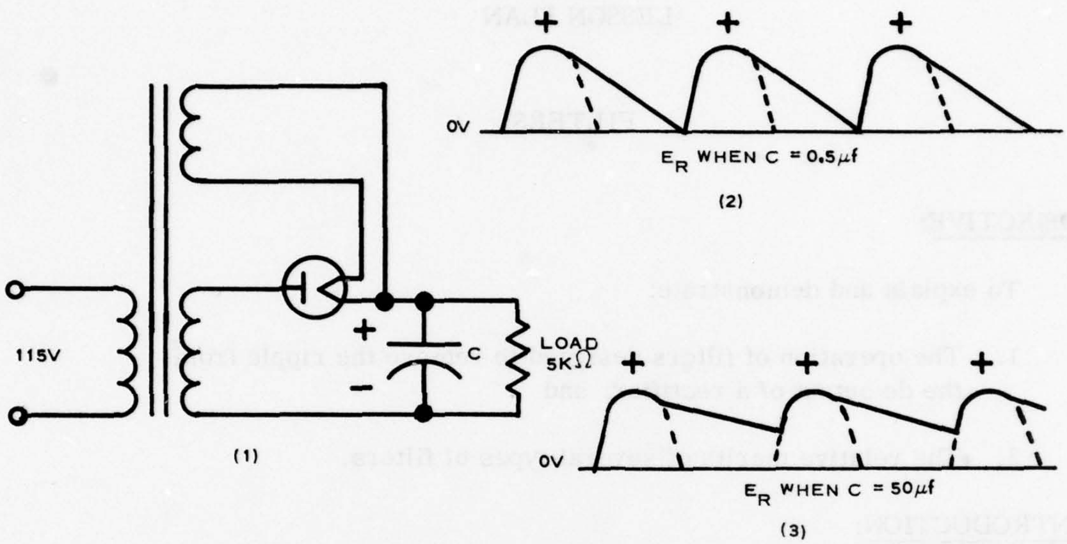

Diagram 121. Half-wave rectifier with filter.

b. When the capacitor C is present, the positive half-cycle of the ac not only produces voltage across the load but also charges the capacitor in the polarity indicated on the diagram.

c. On the negative half-cycles, the voltage across the capacitor tends to go to zero; but before it can do so, the capacitor must discharge (a discharge current must flow). The only path for the discharge current of the capacitor is through the 5,000-ohm load resistor.

d. The result of the foregoing conditions is that there is a voltage drop across the load resistor (because of the discharge current of C) during the time that the diode is not conducting.

e. The waveform shown in diagram 121(2) shows that the capacitor is too small because it discharges almost completely during the nonconducting interval. Since a very large capacitor

does not have time to discharge more than a small amount between the pulses of charging current through the diode, a purer dc voltage is produced.

f. Single capacitors in parallel with the load are practical as filters only when the load passes a very small current, that is, not more than four or five milliamperes.

2. A filter that is more efficient than the single capacitor is the RC, pi-section filter shown in diagram 122. The following statements apply to the filter in diagram 122.

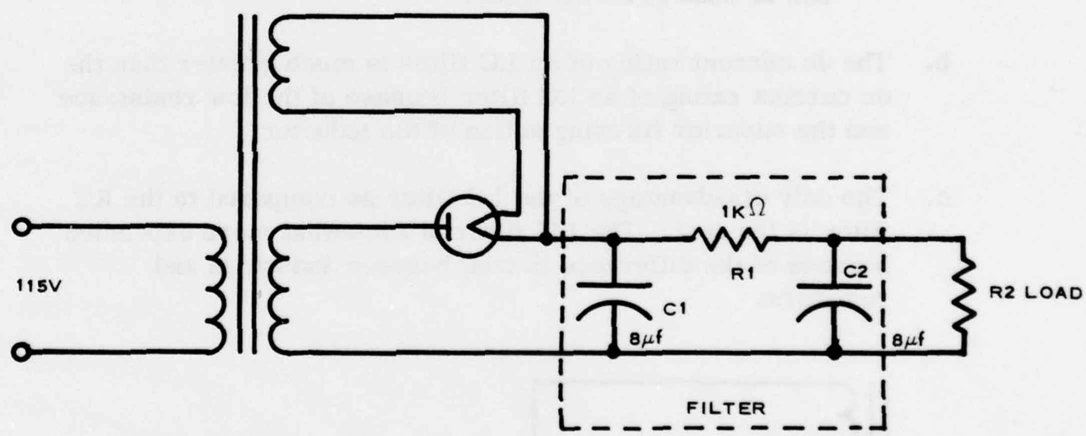

Diagram 122. RC, pi-section filter.

a. The filter is called an RC filter because only resistive and capacitive components are included in the filter.

b. The term "pi-section" refers to the filter circuit configuration which is in the shape of the Greek letter pi (π).

c. The RC, pi-section filter is much more effective in reducing the dc ripple than is a single capacitor, but the filter is used only for loads that require a current that does not exceed 15 or 20 milliamperes. Larger currents would cause an excessive lowering of the dc output voltage because of the drop across resistor R1.

3. The LC, pi-section filter shown in diagram 123 is the filter most often used in practical circuits.

   a. The LC filter is much more efficient in its filtering action than the RC filter for two reasons.

      1) The loss in dc output voltage because of the voltage drop in the resistor is reduced to a negligible amount in the inductor.

      2) The reactance of the inductor to the ripple frequency may be several hundred times the ohmic value of resistance that can be used in an RC filter.

   b. The dc current rating of an LC filter is much greater than the dc current rating of an RC filter because of the low resistance and the superior filtering action of the inductor.

   c. The only disadvantage of the LC filter as compared to the RC filter is the cost. The LC filter is somewhat more expensive because of the difference in cost between inductors and resistors.

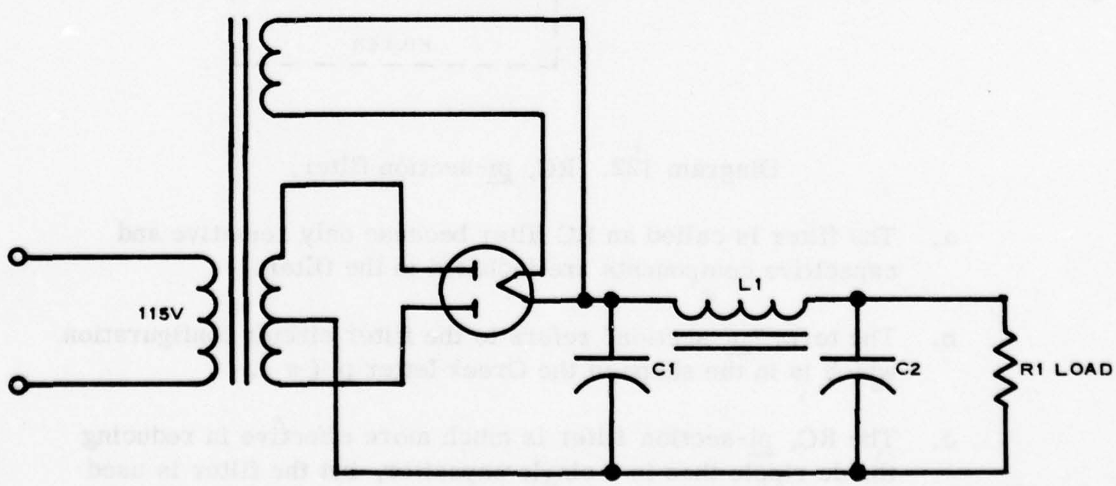

Diagram 123. LC, pi-section filter.

4. The full-wave rectifier shown in diagram 123 produces a ripple frequency that is twice the frequency of the ac power line. The higher ripple frequency, which is easier to filter, plus the improved filtering of the LC circuit, reduces the ripple in the dc output to a very low amplitude.

5. The two filters shown in diagrams 122 and 123 are referred to as capacitor-input filters because each has a capacitor as the first element of the filter circuit (capacitor C1 in both figures).

6. Capacitor-input filters have poor voltage regulation and are used mainly for loads that pass a constant current.

7. If the load on the rectifier and filter is a variable load, the filter is altered to the circuit shown in diagram 124. The addition of the choke L1 to the filter circuit greatly improves the regulation of the dc output voltage since it acts to slow down the discharge of the capacitors and thereby maintains the output voltage at a more constant value.

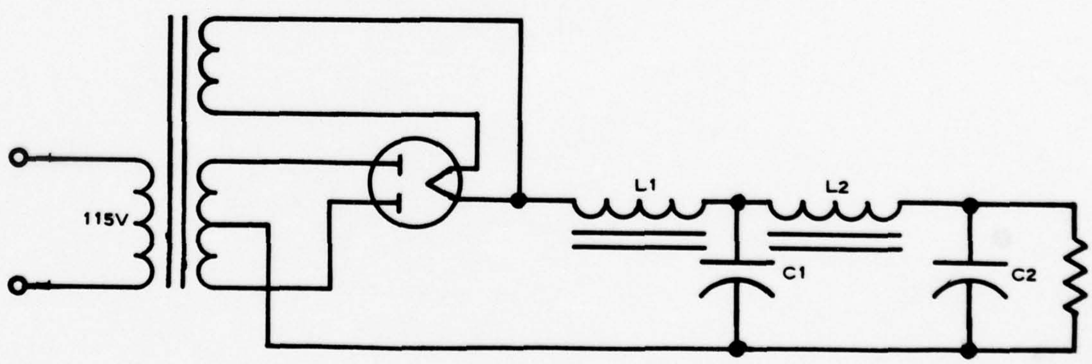

Diagram 124. Choke-input filter.

SUMMARY:

1. The output of any rectifier is a varying dc voltage and must be smoothed out for use in electronic circuits.

2. **Most power supplies employ several sections of filtering in order to supply the smooth and constant dc potentials that are demanded by critical circuitry.**

LESSON PLAN

VOLTAGE DIVIDERS AND POTENTIOMETERS

OBJECTIVE:

To explain and demonstrate by means of diagrams:

1. The purpose of a voltage divider,
2. The calculation of the resistor values in a voltage divider, and
3. The practical uses of a potentiometer.

INTRODUCTION:

1. Many electronic circuits and devices require a voltage source that is lower than the voltage of the available power supply. To provide the lower voltage source, a voltage divider may be used across the output of the high-voltage supply.

2. A potentiometer is a variable voltage divider which supplies an output voltage that can be varied from zero to the maximum input voltage to the potentiometer.

PRESENTATION:

1. A voltage divider consists of two or more resistors connected in series across the output of a power supply. The voltage drop across one of the resistors, which is always lower than the power supply voltage, is utilized as an output voltage to be applied to a load.

2. An example of a voltage divider is shown in diagram 125. Since R1 and R2 are of equal value, one half of the power supply voltage of 300 volts is dropped across each resistor. The 150v drop across R2 may be utilized as a voltage source for any device that requires that voltage.

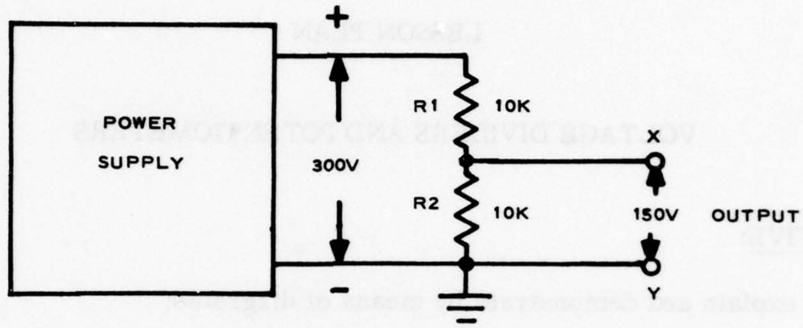

Diagram 125. Voltage divider.

3. The output voltage of the voltage divider in diagram 125 has poor regulation since connecting a load to the output terminals causes the output voltage to decrease. To illustrate the effect of a load on the output voltage of the voltage divider, diagram 126 shows a 10,000-ohm load connected to the output terminals of the circuit in diagram 125.

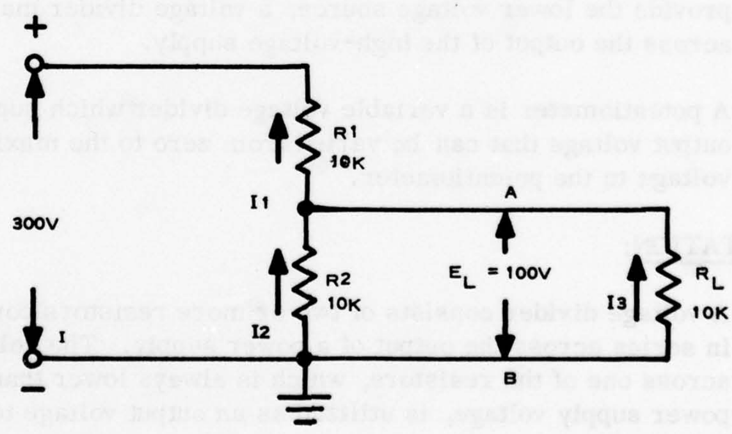

Diagram 126. Voltage divider with load.

4. Diagram 126 shows the value of the output voltage to be 100 volts. This value is verified as follows.

   a. The equivalent resistance of R2 and the load in parallel by equation (8):

$$R_{eq} = \frac{R_z}{N} = \frac{10,000}{2} = 5,000 \text{ ohms.}$$

   b. The total resistance, R_t, connected to the 300v power supply is:

$$R_t = R1 + R_{eq}$$
$$= 10,000 + 5,000 = 15,000 \text{ ohms.}$$

   c. The line current (which is the same as I1) by equation (1) is:

$$I = \frac{E}{R_t}$$
$$= \frac{300}{15,000} = 0.02 \text{ amp.}$$

   d. The drop across R_{eq} by equation (3) is:

$$E_L = I(R_{eq})$$
$$= 0.02 \times 5,000 = 100 \text{ volts.}$$

   e. The 100v drop across R_{eq} is the drop across both R2 and the load. The current through the load is:

$$I3 = \frac{E_L}{R_L} = \frac{100}{10,000} = 0.01 \text{ ampere.}$$

   f. The current through R2 is:

$$I2 = \frac{E}{R2} = \frac{100}{10,000} = 0.01 \text{ ampere.}$$

5. It may be seen that the current through R1 in diagram 126 is equal to the sum of I2 and I3. The current I2 is called the

bleeder current, and it does not pass through the load. Therefore, the bleeder current is wasted; but it is necessary for the operation of the voltage divider.

6. When a voltage divider is designed for some specific application, the load current is usually known, and the bleeder current is assumed to be some definite value. The usual value of bleeder current is about five milliamperes. Therefore, when the load and bleeder currents are known, the values of the resistors in the voltage divider may be calculated by Ohm's law.

7. In the circuit of diagram 127, the load will pass 3 milliamperes when 160 volts is applied. The bleeder current is assumed to be 5 milliamperes. The proper values of R1 and R2 are calculated as follows.

   a. The drop across R2 is 160 volts; and the current through it, I2 is 5 milliamperes. The value of R2 may be calculated by Ohm's law, equation (2):

$$R2 = \frac{E2}{I2} = \frac{160}{0.005} = 32,000 \text{ ohms.}$$

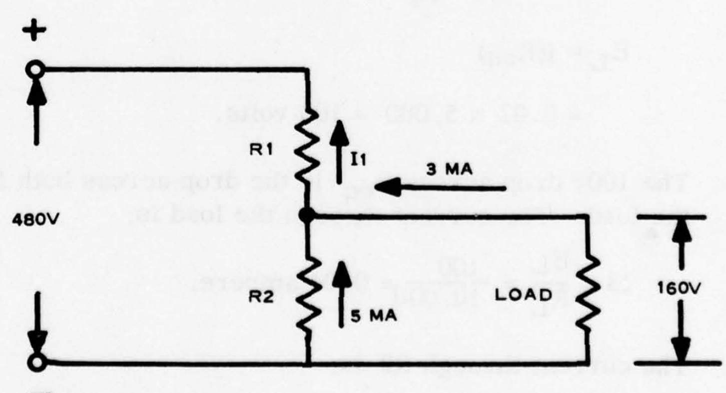

Diagram 127. Voltage divider design.

   b. The current flowing toward the junction between R1 and R2 is the sum of the bleeder current and the load current

(3 + 5 = 8 ma). According to Kirchhoff's current law, there must be as much current flowing away from a junction as there is current flowing toward it. Therefore, the current through R1 must be eight milliamperes.

c. Since the applied voltage is 480 volts and the drop across R2 is 160 volts, the drop across R1 must be the difference between 480 volts and 160 volts by transposing equation (14):

$$E1 = 480 - 160 = 320 \text{ volts.}$$

d. The value of R1 may be calculated by Ohm's law, equation (2):

$$R1 = \frac{E1}{I1} = \frac{320}{0.008} = 40,000 \text{ ohms.}$$

e. From the foregoing calculations it can be seen that a voltage divider which has a 40,000-ohm resistor for R1 will supply 3 milliamperes at 160 volts to the load when the original power supply voltage is 480 volts.

8. Voltage dividers may be designed to supply several output voltages as shown in diagram 128. Assuming a bleeder current of 5 milliamperes, the values of the voltage divider resistors for diagram 128 may be calculated as follows.

a. The bleeder current of 5 milliamperes is the only current through R4, and the drop across R4 is 150 volts. The value of R4 is found by Ohm's law, equation (2):

$$R4 = \frac{E4}{I4} = \frac{150}{0.005} = 30,000 \text{ ohms.}$$

b. The current through R3 is the sum of the bleeder current and the current through load No. 1: 6 milliamperes.

c. The voltage drop across R3 is the difference between 180 volts and 150 volts: 30 volts.

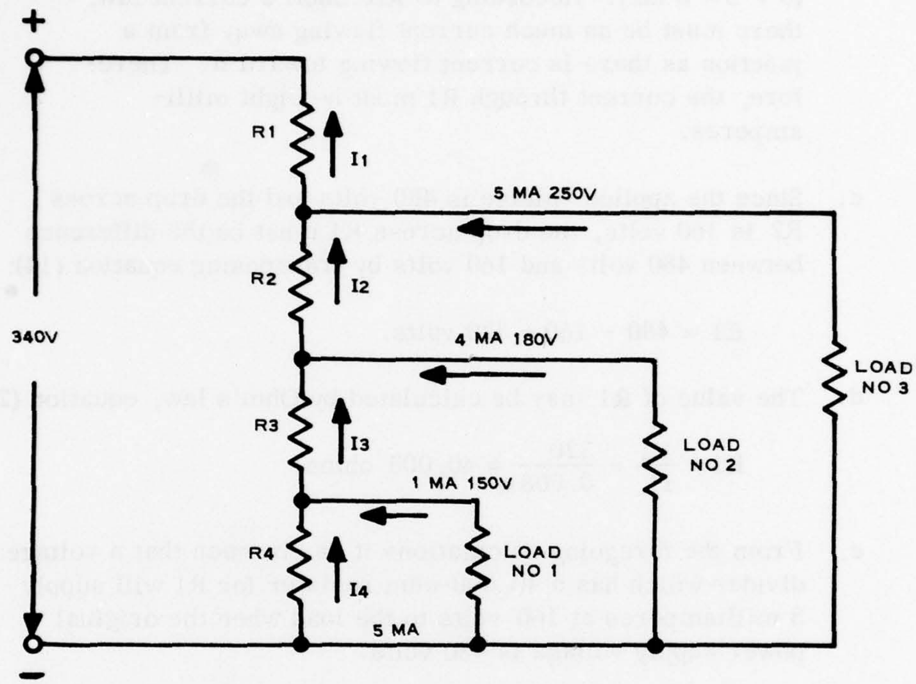

Diagram 128. Voltage divider circuit.

d. The value of R3 by equation (2) is:

$$R3 = \frac{E3}{I3} = \frac{30}{0.006} = 5,000 \text{ ohms.}$$

e. The current through R2 is the sum of I3 and the load current passed by load No. 2: 10 milliamperes.

f. The voltage drop across R2 is the difference between 250 volts and 180 volts: 70 volts.

g. The value of R2 is:

$$R2 = \frac{E2}{I2} = \frac{70}{0.01} = 7,000 \text{ ohms.}$$

h. The current through R1 is the sum of I2 and the current passed by load No. 3: 15 milliamperes.

i. The voltage drop across R1 is the difference between 340 volts and 250 volts: 90 volts.

j. The value of R1 is:

$$R1 = \frac{E1}{I1} = \frac{90}{0.015} = 6,000 \text{ ohms.}$$

k. The values of the four resistors calculated above for the voltage divider of diagram 128 will supply the indicated currents at the indicated voltages to the three loads.

9. The problems in diagram 129 are exercises for the student. Find the unknown quantities indicated below each circuit.

10. The voltage dividers that have been illustrated thus far have had dc voltage sources. All illustrations and explanations will apply equally well to ac voltages and currents. The only difference between ac and dc in the illustrations and calculations is that no polarities would be indicated for ac.

11. A potentiometer is a voltage divider whose output may be varied manually from zero to the full supply voltage. Diagram 130 shows a potentiometer which indicates that the output voltage is the voltage drop across that part of the potentiometer resistance between the sliding contact and ground. When the sliding contact is moved to the grounded end of the resistor, the output voltage is zero. When the contact is moved to the top of the potentiometer resistance, the output voltage is equal to the power-supply voltage.

12. The advantage of the potentiometer is that the output voltage may be adjusted to any desired value between zero and the input voltage.

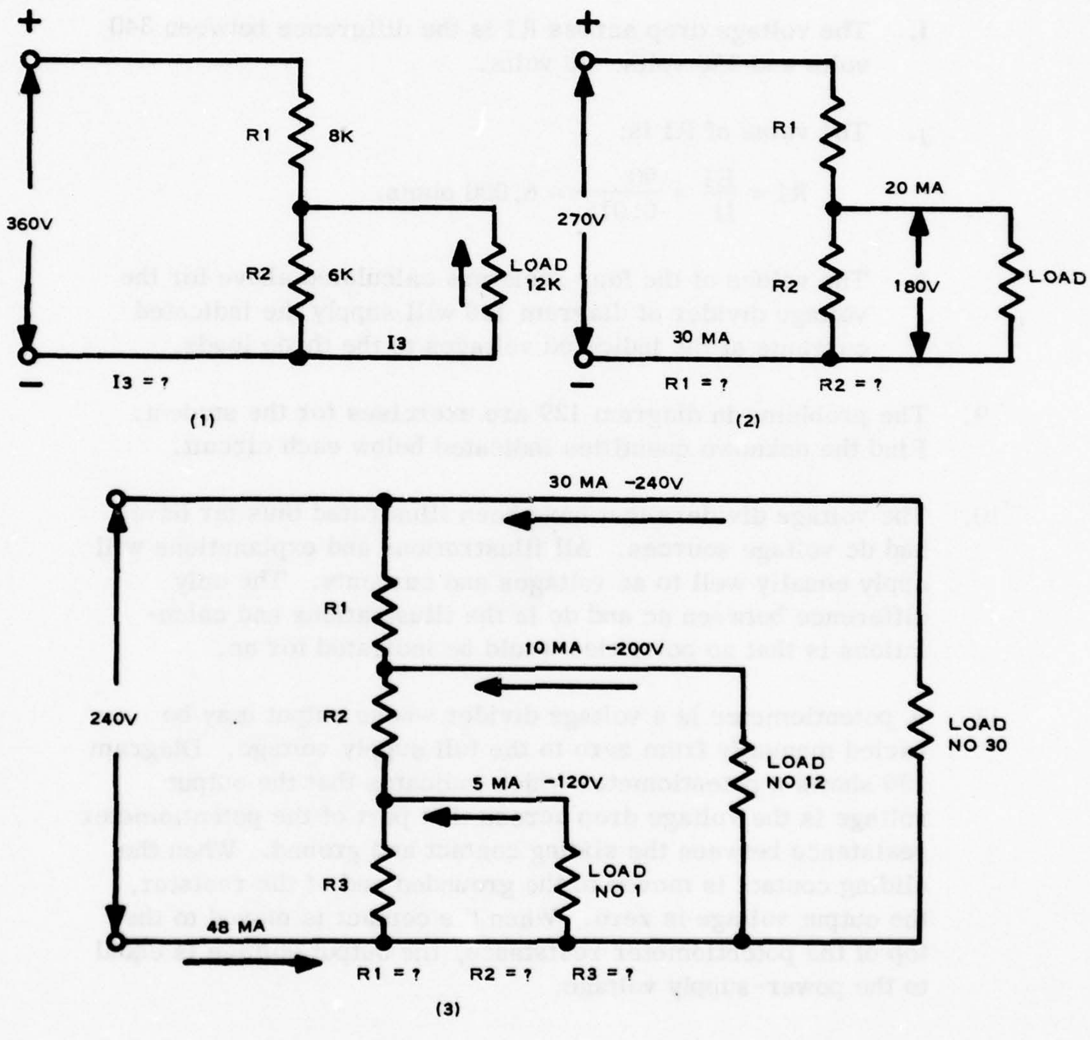

Diagram 129. Voltage divider problems.

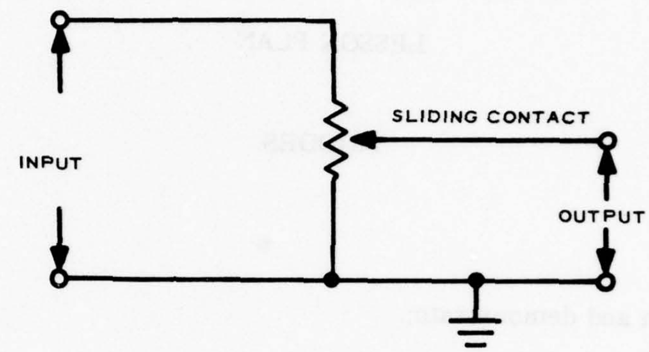

Diagram 130. Potentiometer.

SUMMARY:

1. It is often impractical to design power supplies that will furnish all the various voltages necessary in the operation of electronic circuits.

2. A voltage divider is frequently used to drop the supply voltage to a usable value.

3. The resistance necessary to obtain any given voltage from any given supply voltage is easily calculated. The student should become familiar with the simple mathematics involved in their computation since almost any circuit he encounters will contain several voltage dividers.

IF-24

LESSON PLAN

TRIODES

OBJECTIVE:

To explain and demonstrate:

1. The development of the triode from the diode,
2. The effect of grid-to-cathode voltage on the cathode-to-plate resistance of a triode,
3. The relationship between the amplification factor of a tube and the possible gain of the tube in a practical circuit, and
4. How a triode tube amplifies.

INTRODUCTION:

1. In 1907, Lee De Forest introduced a third electrode in the diode to produce the triode, the first amplifier vacuum tube.
2. The third element in the vacuum tube is called the control grid because it functions to control the electron flow from cathode to plate.
3. The control grid is a mesh of fine wires located between cathode and plate through which electrons must pass to reach the plate.
4. Many modifications of the basic triode have been made since the triode was first developed, but the triode is still one of the most important amplifier tubes in use today.

PRESENTATION:

> INSTRUCTOR'S NOTE: Have in the classroom a large mock-up demonstrator for vacuum tubes, and have an electronic triode demonstrator (with the fluorescent plate) to show the construction and operation of triodes.

1. In the diode there exists an electrostatic field between the cathode and plate when the plate is positive with respect to the cathode (diag 131).

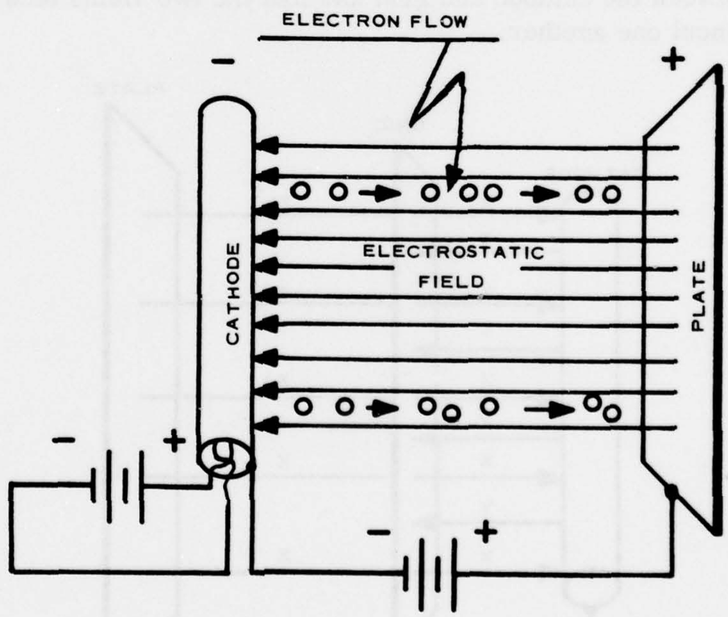

Diagram 131. Electrostatic field in a diode.

2. Electrons which leave the surface of the cathode by means of thermionic emission tend to move through the electrostatic field toward the plate. It is the electrostatic field from the positive plate which attracts negative electrons.

3. When a grid of wires, with relatively large spaces between the wires, is placed in the electron path between the cathode and plate (diag 132), the electrostatic field from the plate (see arrows marked "X" in diagram 132) extends through the spaces in the grid to attract electrons from the space charge (cloud of electrons near the cathode surface) toward the plate.

4. The grid is normally held negative with respect to the cathode; therefore, there will be an electrostatic field between the cathode and grid. This is indicated by the arrows marked "Y" in diagram 132.

5. It will be noted that the two electrostatic fields plate-to-cathode X and cathode-to-grid Y are in opposite directions in the space between the cathode and grid and that the two fields tend to cancel one another.

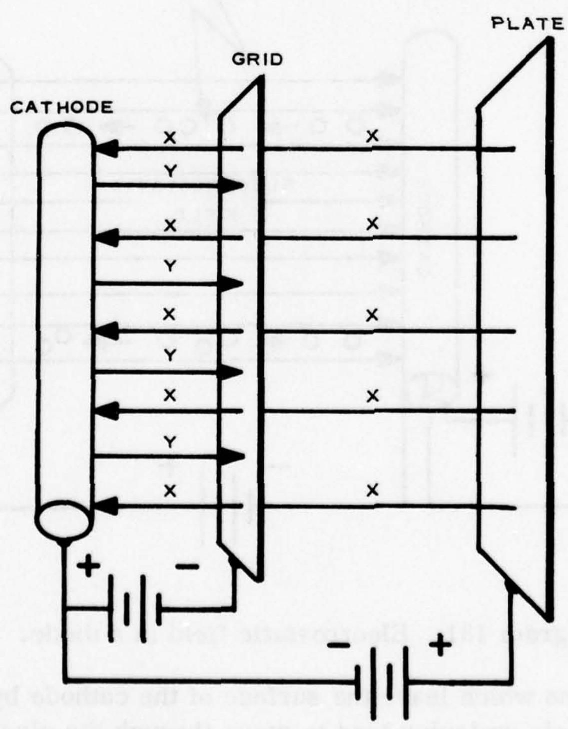

Diagram 132. Electrostatic fields.

6. If the grid is made only slightly negative with respect to the cathode, the field from the plate is weakened, but not eliminated; the attraction of the plate for electrons is reduced; and fewer electrons flow to the plate than would flow if the grid were absent.

7. If the grid is made more and more negative with respect to the cathode, the neutralizing effect of the cathode-to-grid field on the cathode-to-plate field causes fewer and fewer electrons to pass through the grid to the plate.

8. If the grid is made sufficiently negative with respect to the cathode, the field between cathode and grid completely neutralizes the field from the plate, and the plate receives no electrons from the space charge.

9. That voltage on the grid which just stops the flow of electrons to the plate is called the cutoff voltage. Any greater negative voltage on the grid has no effect.

INSTRUCTOR'S NOTE: Use the electronic triode demonstrator with the fluorescent plate to show how the grid controls plate current.

10. From the foregoing statements, it may be seen that negative voltages on the grid control plate current. Since no current flows to or from the grid, the grid expends no power. No electrons will strike the grid because the grid is negative and repels the negative electrons. No electrons can leave the surface of the grid because the grid is cold.

11. In a triode, the conducting path between the cathode and plate may be considered as a resistance which is controlled by the grid-to-cathode voltage. The more negative the grid, the higher the resistance between cathode and plate. When the grid is at the cutoff voltage, the resistance between cathode and plate is infinity.

12. Diagram 133 shows the triode symbol used in schematic diagrams. The filament and filament leads are usually omitted to simplify the diagram.

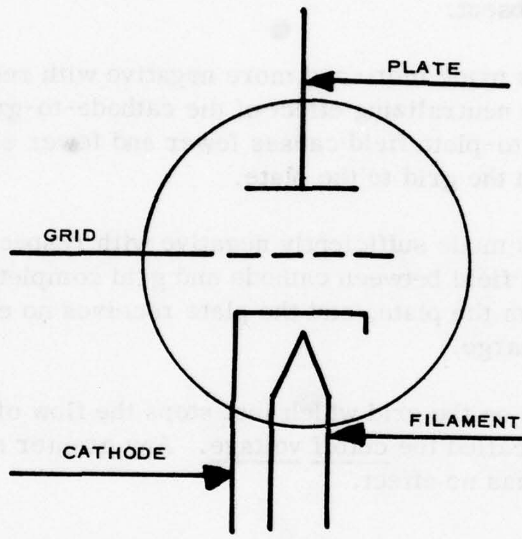

Diagram 133. Triode symbol.

13. An amplifier is a vacuum-tube circuit which receives an ac voltage of low amplitude. A triode may be an amplifier when connected to the proper circuit components and proper voltages.

14. An example of how a triode may function as an amplifier is shown in diagram 134(1) and 134(2).

15. The following statements refer to the circuit of diagram 134(1) and waveforms in diagram 134(2).

    a. The dc power supply voltage E_b is 60 volts.

    b. The 10,000-ohm resistor R_L between the power supply and the plate of the tube is referred to as the plate load resistor.

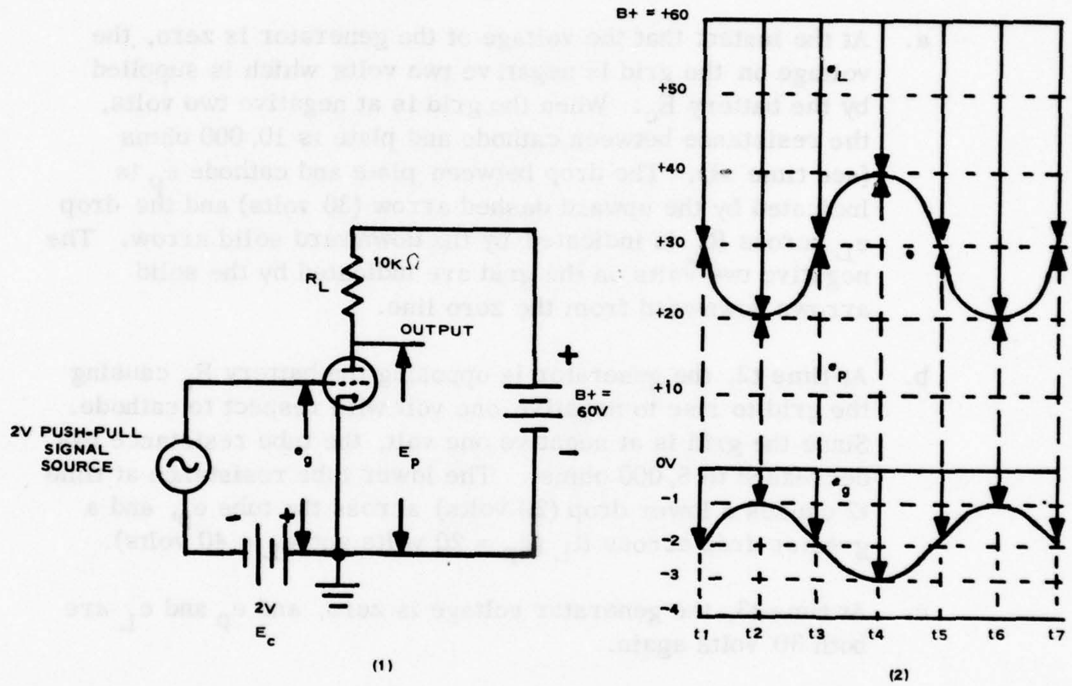

Diagram 134. Triode amplifier operation.

c. The cathcde-to-plate resistance R_{kp} of the tube is in series with R_L, and the sum of the voltage drops across the two resistances is always equal to 60 volts E_b.

d. The 2v battery E_c holds the grid of the tube at an average of -2 volts with respect to cathode.

e. The 2-volt, peak-to-peak, signal source is represented as an ac cycle of the generator output The generator is aiding the 2v battery E_c and causing the grid to be at negative three volts (see time t3 in diagram 134(2)) with respect to the cathode. On the other half-cycle, the generator voltage is opposing the 2v battery and causing the grid to be at negative one volt with respect to cathode.

16. The following statements refer to the operation of the tube in in diagram 134(1) as an amplifier.

a. At the instant that the voltage of the generator is zero, the voltage on the grid is negative two volts which is supplied by the battery E_c. When the grid is at negative two volts, the resistance between cathode and plate is 10,000 ohms (see time t1). The drop between plate and cathode e_p is indicated by the upward dashed arrow (30 volts) and the drop e_L across R_L is indicated by the downward solid arrow. The negative two volts on the grid are indicated by the solid arrows downward from the zero line.

b. At time t2, the generator is opposing the battery E_c causing the grid to rise to negative one volt with respect to cathode. Since the grid is at negative one volt, the tube resistance has decreased to 5,000 ohms. The lower tube resistance at time t2 causes a lower drop (20 volts) across the tube e_p, and a greater drop across R_L (e_p = 20 volts and e_L = 40 volts).

c. At time t3, the generator voltage is zero, and e_p and e_L are both 30 volts again.

d. At time t4, the generator voltage is aiding the battery E_c, causing the grid to fall to negative three volts with respect to cathode. When the grid is at negative three volts, the cathode-to-plate resistance R_p is 2,000 ohms. The increased resistance at R_p causes a greater drop between cathode and plate and a lower drop across R_L (e_p = 40 volts and e_L = 20 volts).

e. At time t5, both e_p and e_L are 30 volts.

f. From the foregoing it may be seen that, for any change of voltage occurring in the grid, a change ten times as great occurs on the plate. The gain in signal amplitude is ten.

g. The signal applied to the grid by the signal generator is a sine wave as is the signal developed on the plate; however, the signal developed on the plate is inverted, or shifted 180 electrical degrees, with respect to the input signal.

h. The amplifier not only amplifies the signal but inverts it.

i. The gain of an amplifier A is the ratio of the ac output to the input signal amplitude:

$$A = \frac{E_{out}}{E_{in}}. \tag{54}$$

j. *The gain of the amplifier in diagram 134(1) is:*

$$A = \frac{20}{2} = \frac{10}{1} = 10.$$

17. Tube manufacturers supply a tube manual which indicates the relative merits of amplifier tubes by means of a figure called the amplification factor, μ (mu). The amplification factor indicates the theoretical maximum possible gain of a given tube, a gain which can be approached but never attained. As *an example, a 6J5 triode tube has an amplification factor of* 20, but in practical circuits the actual gain is less than 20 usually between 15 and 18.

<u>SUMMARY</u>:

1. The triode is the simplest of amplifier tubes and consists of only three elements; cathode, grid, and plate.

   a. The current that is passed by the tube is controlled by the small potential applied to the grid.

   b. It is this property that allows the triode to be used for amplification of signals.

2. The student must not consider it essential that he memorize the characteristics of tubes since there are many manuals devoted to this subject to which he can easily refer.

IF-25

LESSON PLAN

MULTIELEMENT TUBES

OBJECTIVE:

To explain and demonstrate:

1. The disadvantages of the triode that led to the development of the tetrode,
2. The peculiarities that led to the development of the pentode,
3. The limitations of the pentode that led to the development of the beam-power tube,
4. Dual and special purpose tubes, and
5. Schematic symbols for all general-purpose tubes.

INTRODUCTION:

1. Triode tubes have characteristics which enable them to perform many amplifying functions better or more economically than other tube types; but some triode peculiarities cause them to be unsuitable, or extremely difficult to use, in certain amplifying applications.
2. The development of multielement tubes was the result of efforts to reduce or eliminate the limitations of the triode, and these improved tubes were found to be superior in gain and power-handling capabilities for a given plate area.
3. Dual tubes are simply two sets of elements in a single evacuated envelope, reducing the space and wiring that would be necessary if separate tubes were used. Dual tubes may contain, for example, two independent triodes, or a triode and a diode, or perhaps a triode and a pentode, both in the same envelope.

PRESENTATION:

> INSTRUCTOR'S NOTE: Use a large, vacuum-tube demonstrator to show the progressive development of vacuum tubes.

1. The triode tube has one outstanding peculiarity which makes it difficult to use as an amplifier for very high ac frequencies, capacitance between the control grid and the plate (the control grid in any tube is the grid that is closest to the cathode).
2. To reduce the capacitance between the control grid and the plate, a second grid is introduced between these two elements. This second grid is called the screen grid and is normally operated at a constant, positive potential with respect to the cathode.
3. The tube with two grids (control grid and screen grid) is called a tetrode.
4. The schematic symbol for a tetrode is shown in diagram 135.

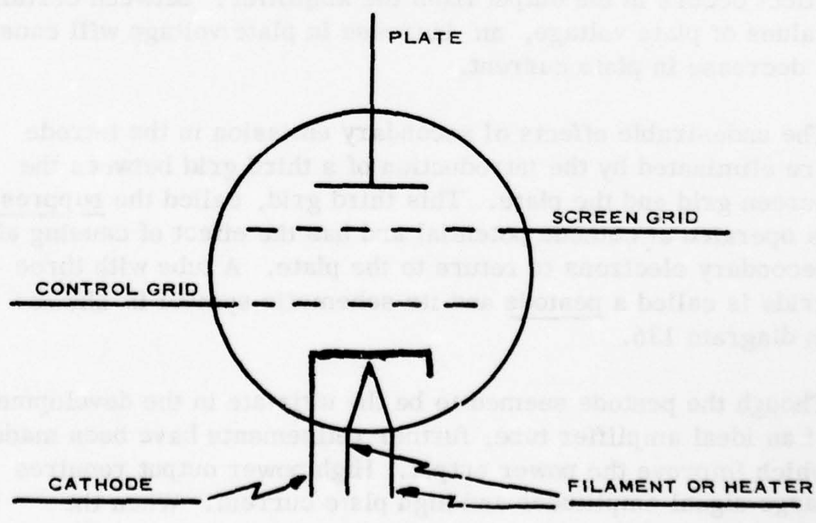

Diagram 135. Tetrode.

5. The screen grid in the tetrode enables the tube to have higher amplification and much greater power output than a triode with the same plate area. The screen collects only a small percentage of the electrons which leave the space charge; the larger percentage of electrons pass through the spaces between the screen-grid wires and strike the plate. The electrons reaching the plate constitute the usable current which develops the output signal across the plate load resistor.

6. The electrons which pass through the screen and strike the plate (called primary electrons) may hit the plate with such great velocity that other electrons on the plate surface are knocked off. These emitted electrons from the plate are called secondary electrons and may be greater in number than primary electrons. The emission of electrons from the plate owing to bombardment by primary electrons is called secondary emission.

7. If the plate is positive with respect to the screen, secondary electrons will return to the plate; but during that part of the ac cycle when the plate is negative with respect to the screen, the secondary electrons will go to the screen.

8. When secondary electrons go to the screen, a very undesirable effect occurs in the output from the amplifier. Between certain values of plate voltage, an increase in plate voltage will cause a decrease in plate current.

9. The undesirable effects of secondary emission in the tetrode are eliminated by the introduction of a third grid between the screen grid and the plate. This third grid, called the suppressor, is operated at cathode potential and has the effect of causing all secondary electrons to return to the plate. A tube with three grids is called a pentode and its schematic symbol is shown in diagram 136.

10. Though the pentode seemed to be the ultimate in the development of an ideal amplifier tube, further refinements have been made which improve the power output. High power output requires large signal amplitudes and high plate current. When the signal amplitude on the plate of a pentode exceeds a certain

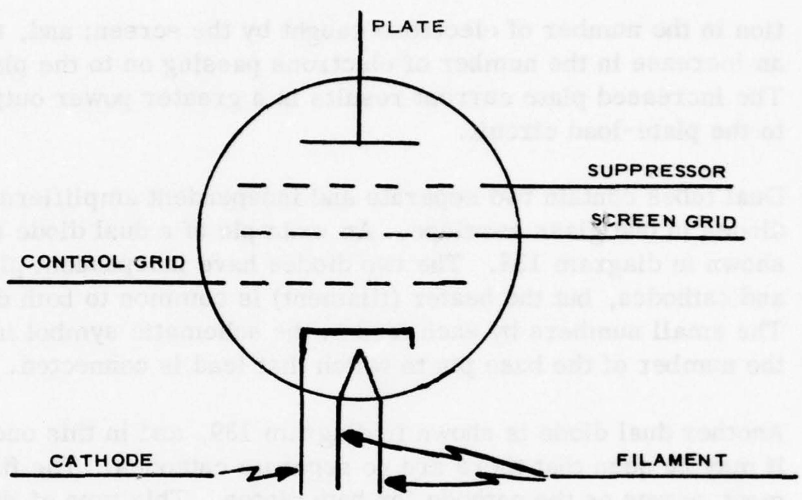

Diagram 136. Pentode.

value, a small amount of third harmonic distortion occurs in the output signal. Investigation proved that the third harmonic distortion was caused by the suppressor action's being uneven over the plate surface. The unevenness was caused by having alternate wires and spaces between wires in the suppressor grid.

11. To produce a more even suppressor action over the entire cross-section of the electron path, the beam-power tube was developed (diag 137).

12. The beam-forming plates of the beam-power tube are operated at cathode potential and cause the electrons to concentrate into a narrow beam just before they strike the plate. This narrow beam of electrons is dense and repels secondary electrons, causing them to return to the plate. Thus, suppressor action is produced without using a suppressor grid.

13. A further improvement in the beam-power tube was made by alining the screen-grid wires with the control-grid wires so that the screen is in the "shadow" of the control grid. The result of alining the screen grid with the control grid is a reduc-

tion in the number of electrons caught by the screen; and, thus, an increase in the number of electrons passing on to the plate. The increased plate current results in a greater power output to the plate-load circuit.

14. Dual tubes contain two separate and independent amplifiers or diodes in one glass envelope. An example of a dual diode is shown in diagram 138. The two diodes have independent plates and cathodes, but the heater (filament) is common to both diodes. The small numbers by each lead in the schematic symbol indicate the number of the base pin to which that lead is connected.

15. Another dual diode is shown in diagram 139, and in this one it may be seen that there are no separate cathodes. The filament serves as the cathode for both plates. This type of dual diode is commonly used as a power rectifier.

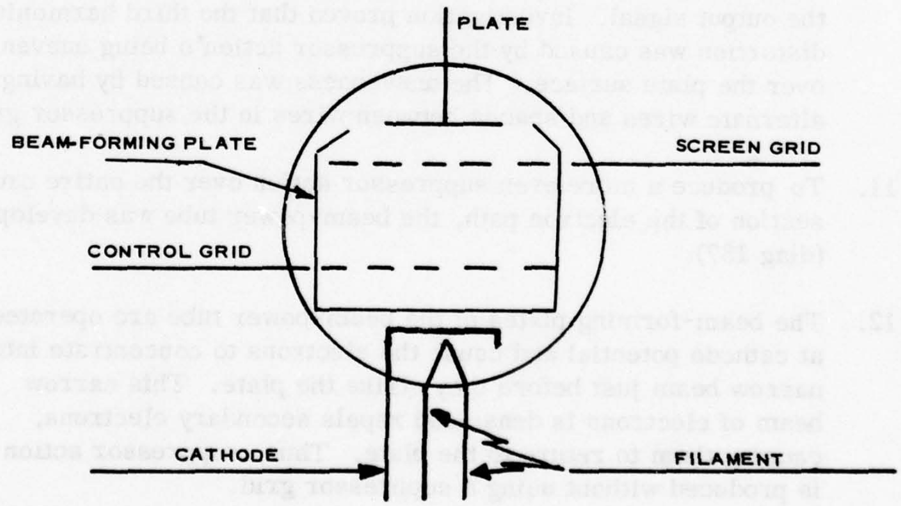

Diagram 137. Beam-power tube.

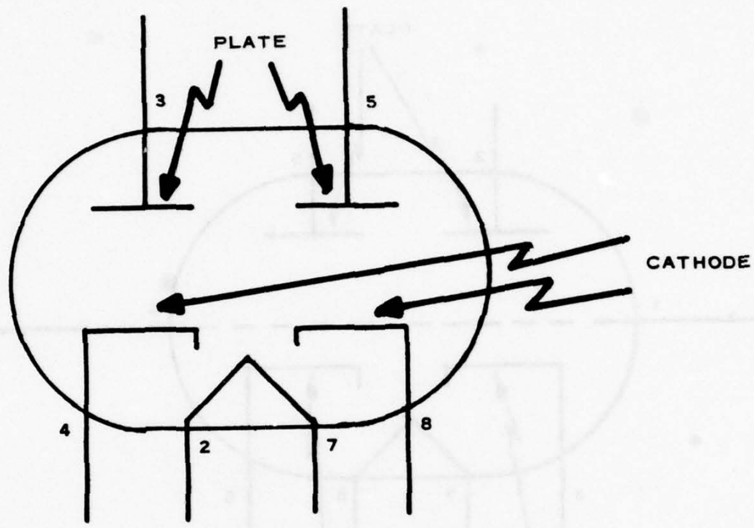

Diagram 138. 6H6 diode.

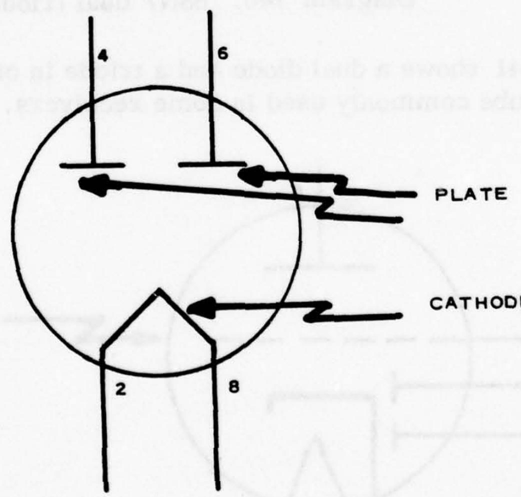

Diagram 139. 5U4 rectifier.

16. A very convenient and commonly used dual tube is the dual triode shown in diagram 140. The heater is common to both triodes; but the grids, plates, and cathodes form two completely independent amplifiers. This tube is used extensively in radar sets.

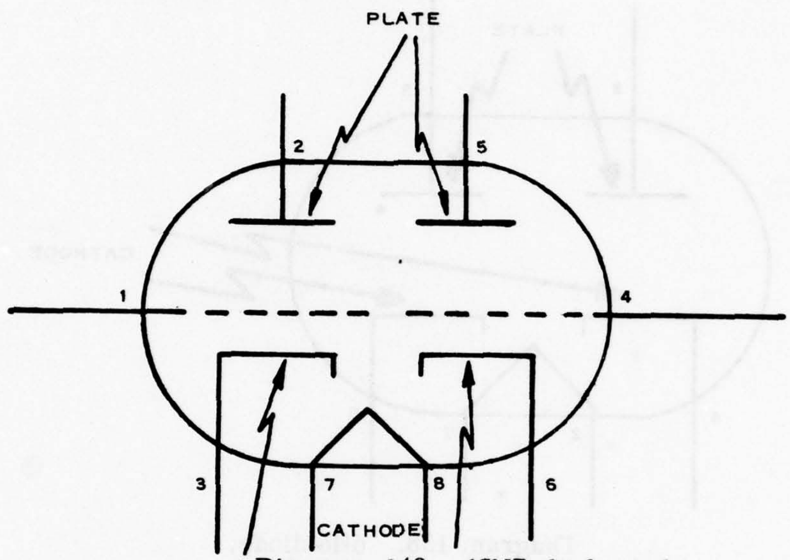

Diagram 140. 6SN7 dual triode.

17. Diagram 141 shows a dual diode and a triode in one envelope. This is a tube commonly used in home receivers.

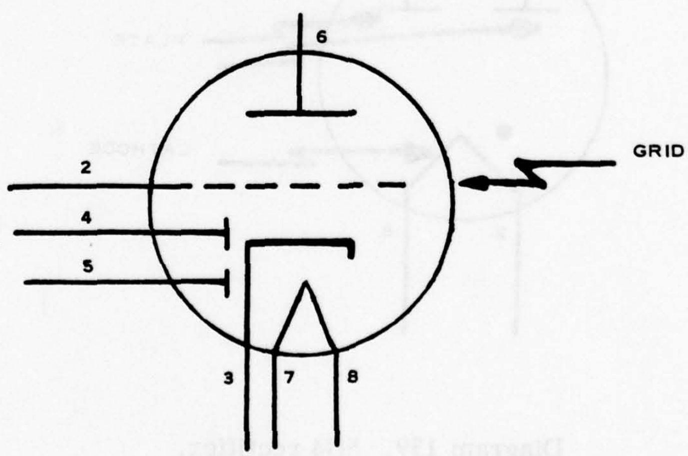

Diagram 141. 6SQ7 detector-amplifier.

18. The dual tube shown in diagram 142 consists of a triode and a pentode. This is a general-purpose tube and may be used where two amplifier tubes of the included types are needed.

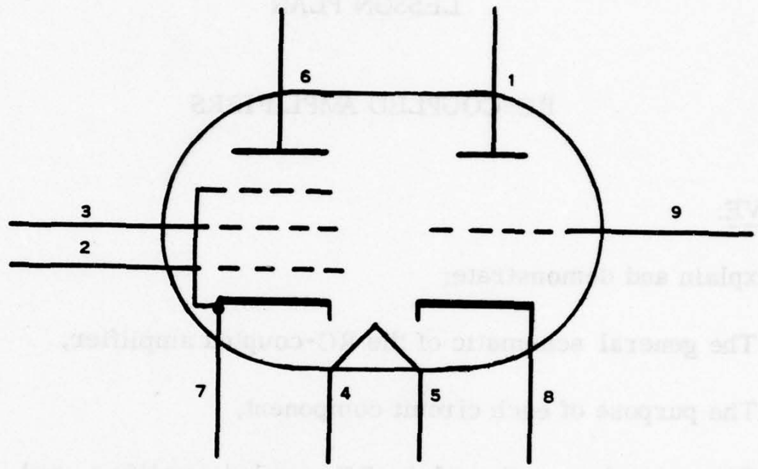

Diagram 142. 6U8 triode-pentode.

SUMMARY:

1. Many desirable characteristics can be obtained in a vacuum tube by the use of more than one grid.

2. The most common multielement tube is the tetrode (four elements).

3. Other tubes containing as many as eight elements are available for special purposes.

IF-26

LESSON PLAN

RC-COUPLED AMPLIFIERS

OBJECTIVE:

To explain and demonstrate:

1. The general schematic of the RC-coupled amplifier,

2. The purpose of each circuit component,

3. The normal operation of the RC-coupled amplifier, and

4. The frequency response curve and the causes of high-frequency and low-frequency loss of gain.

INTRODUCTION:

> INSTRUCTOR'S NOTE: Use a classroom demonstration board for showing the input and output waveforms of RC-coupled amplifiers.

The RC-coupled amplifier is the amplifier most frequently used for amplifying audio and video frequencies.

PRESENTATION:

1. The RC-coupled amplifier is so called because only resistors and capacitors are used to develop the signal in the plate circuit and pass the signal on to the next amplifier stage.

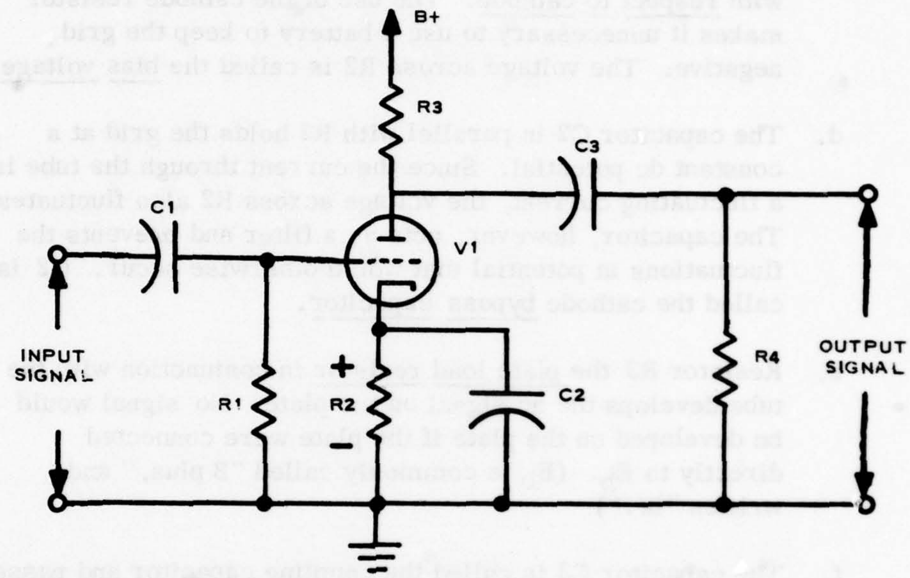

Diagram 143. RC-coupled amplifier.

2. The circuit of an RC-coupled amplifier is shown in diagram 143.

a. C1 and R1 make up the input-coupling circuit from the source of the ac signal. These two components have nothing to do with the amplification of the signal by the tube V1.

b. The resistor R1 holds the grid at an average ground potential, and the ac voltage on the grid is alternating with respect to ground.

c. The resistor R2 holds the cathode at a positive potential with respect to ground because of plate current flowing from ground, through R2, to the cathode. This current produces a small dc voltage, the polarity of which is indicated by the signs on each end of R2. In the lesson on triodes, it was stated that the grid must normally operate at a potential that is negative with respect to the cathode. Since the cathode is at a few volts positive with respect to ground and the grid is at ground potential, the grid is negative

with respect to cathode. The use of the cathode resistor makes it unnecessary to use a battery to keep the grid negative. The voltage across R2 is called the bias voltage.

d. The capacitor C2 in parallel with R2 holds the grid at a constant dc potential. Since the current through the tube is a fluctuating current, the voltage across R2 also fluctuates. The capacitor, however, acts as a filter and prevents the fluctuations in potential that would otherwise occur. C2 is called the cathode bypass capacitor.

e. Resistor R3 the plate load resistor in conjunction with the tube develops the ac signal on the plate. No signal would be developed on the plate if the plate were connected directly to E_b. (E_b is commonly called "B plus," and written "B+.")

f. The capacitor C3 is called the coupling capacitor and passes the ac component of the signal on the plate to the grid of the next amplifier tube. The actual voltage on the plate of V1 is a fluctuating dc, but the capacitor C3 blocks the dc component, and passes the ac component. C3 and R4 form a coupling circuit in exactly the same manner as C1 and R1. The ac voltage that appears across R4 is an alternating voltage like that across R1.

3. The following description of the detailed operation of the RC-coupled amplifier refers to the circuit shown in diagram 144. The tube V2 is an RC amplifier which receives a small ac signal from the plate of V1, amplifies the signal, and passes it by means of C3 and R4 to the grid of V3. The following statements describe the static condition (no signal present) and operating condition (signal amplified) of the circuit.

a. When no signal is passing through the amplifier, the only voltages present are constant dc voltages (with respect to ground).

b. With no signal present, the plate of V1 is at +170 volts, the grid of V2 is at ground, the cathode of V2 is at +6 volts, the plate of V2 is at +170 volts, and the grid of V3 is at ground (zero).

c. If a signal that has a peak-to-peak amplitude of 4 volts is developed on the plate of V1, the plate of V1 will fluctuate between 172 volts and 168 volts as shown in diagram 145(1).

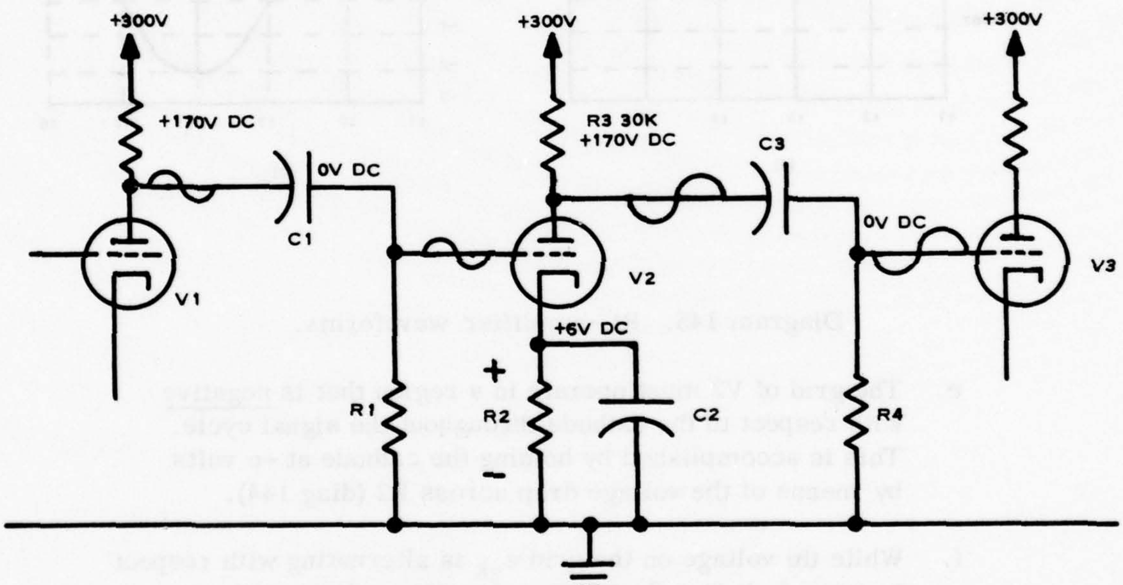

Diagram 144. RC-amplifier operation.

d. The ac component of the voltage on the plate of V1 is passed by capacitor C1 (diag 144) to the grid of V2, but the dc component (170 volts) is blocked. At the grid of V2 there will appear only an alternating voltage (see the sine wave in diagram 145(2)) which swings positive and negative with respect to ground.

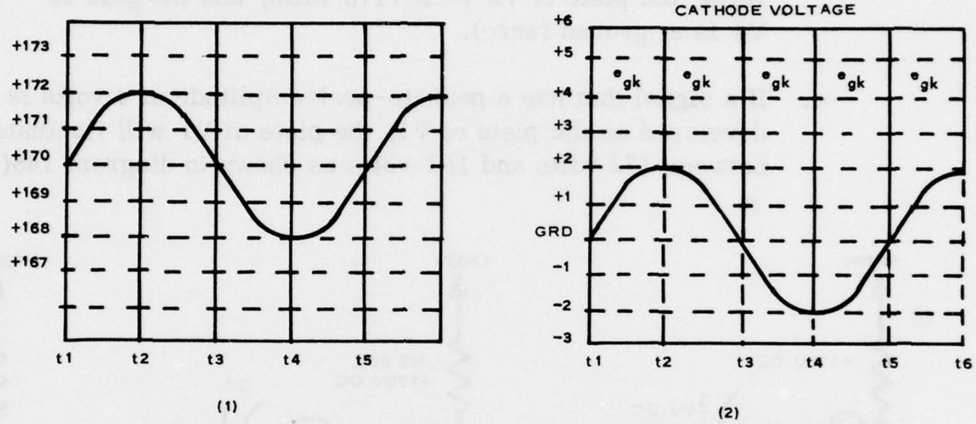

Diagram 145. RC-amplifier waveforms.

e. The grid of V2 must operate in a region that is negative with respect to the cathode throughout the signal cycle. This is accomplished by holding the cathode at +6 volts by means of the voltage drop across R2 (diag 144).

f. While the voltage on the grid e_{gk} is alternating with respect to ground, it is a fluctuating, negative voltage with respect to the cathode. As shown in diagram 145(2), at time t1 the grid of V2 is -6 volts with respect to cathode; at time t2 the grid is -4 volts; at time t3 the grid is -6 volts; at time t4 the grid is -8 volts; and at time t5 the grid is -6 volts.

g. The variations of voltage with respect to cathode on the grid of V2 control the resistance between the cathode and the plate of that tube, and the variation of resistance causes the voltage on the plate to fluctuate in the manner shown in diagram 146. The times t1, t2, etc., are the same instants of time in all diagrams.

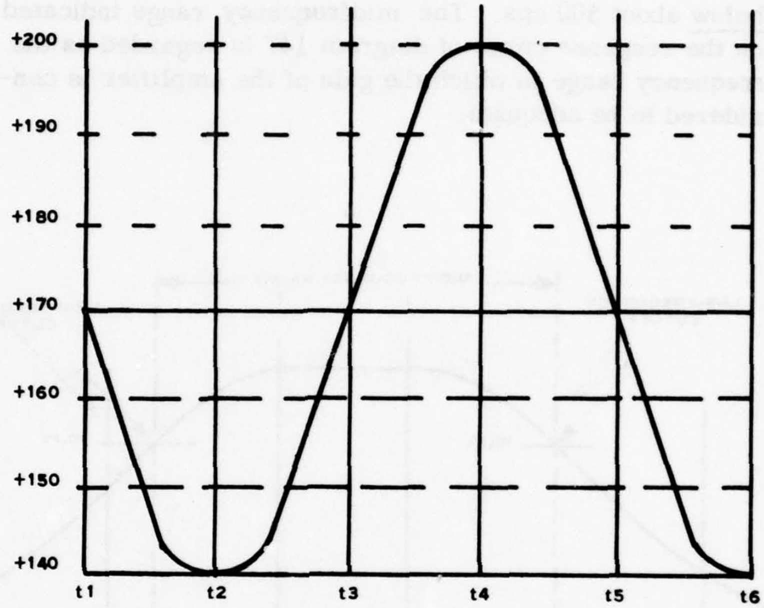

Diagram 146. Plate waveform.

h. An important characteristic of the tube V2 is seen by comparing the grid-voltage waveform in diagram 145(2) and the plate-voltage waveform in diagram 146: The signal on the plate swings in a negative direction (downward) when the grid swings in a positive direction (upward). This reversal of signal direction means that the signal on the plate is 180° out of phase with the signal on the grid.

i. The tube V2 has a gain that is found by equation (54):

$$A = \frac{E_{out}}{E_{in}} = \frac{60}{4} = 15$$

4. The gain of an RC-coupled amplifier is constant over a wide range of frequencies but does have limits at both low and high frequencies. Diagram 147 illustrates a typical frequency response curve for an RC-coupled amplifier. It may be seen in diagram 147 that the gain of the amplifier begins to decrease at frequencies above 10,000 cps and decreases at frequencies

below about 500 cps. The midfrequency range indicated on the response curve of diagram 147 is regarded as the frequency range in which the gain of the amplifier is considered to be adequate.

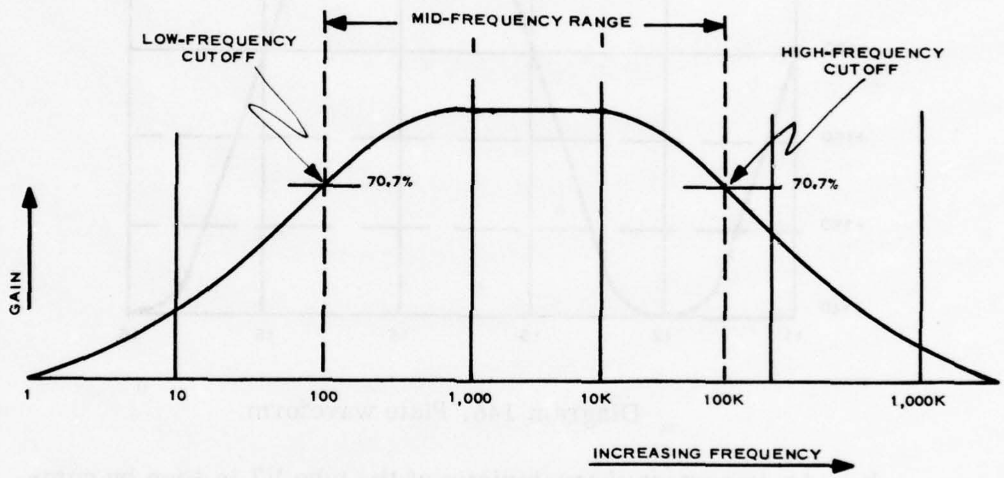

Diagram 147. Frequency response curve.

5. The high-frequency cutoff point is the high frequency at which the gain of the amplifier falls to 70.7 percent of the maximum gain in the midfrequency range. The low-frequency cutoff point is the low frequency at which the gain falls to 70.7 percent of the maximum gain.

6. The high-frequency and low-frequency cutoff points may also be called the half-power points.

7. The causes of the loss in gain at high and low frequencies are explained by referring to the circuit of diagram 148.

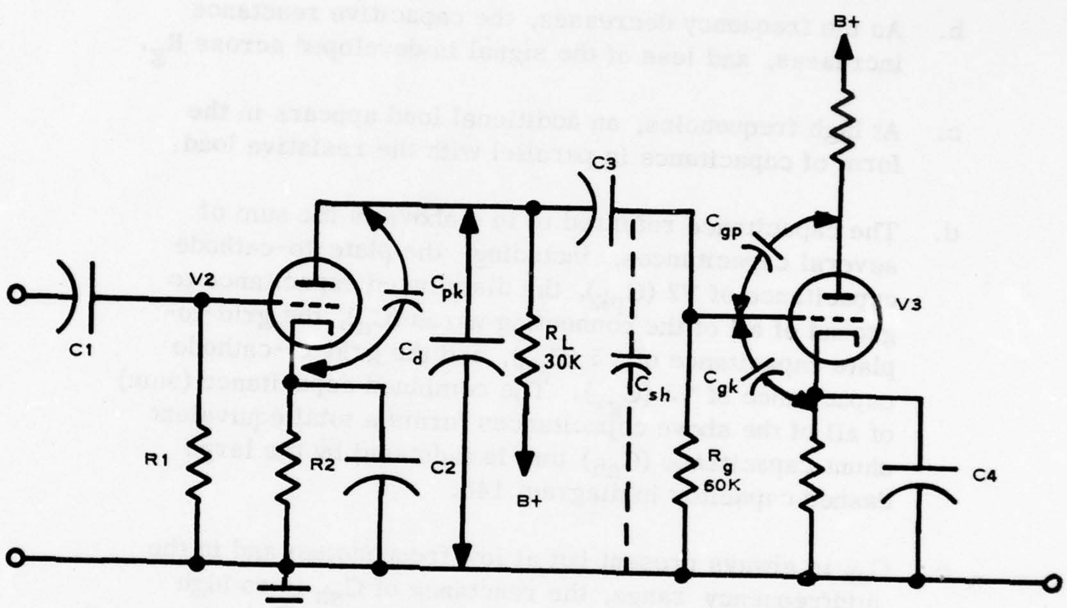

Diagram 148. Shunt capacitance in amplifiers.

a. The input circuit to V3 may be thought of as a voltage divider consisting of X_C capacitive reactance and R_g as shown in diagram 149.

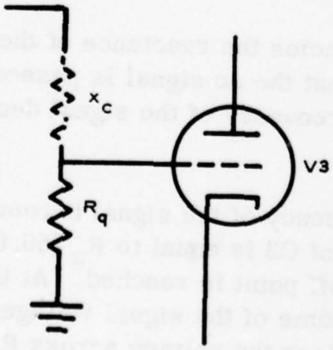

Diagram 149. Effective capacitive input reactance.

b. As the frequency decreases, the capacitive reactance increases, and less of the signal is developed across R_g.

c. At high frequencies, an additional load appears in the form of capacitance in parallel with the resistive load.

d. The capacitance referred to in c above is the sum of several capacitances, including: the plate-to-cathode capacitance of V2 (C_{pk}), the distributed capacitance to ground of all of the connecting wires (C_d), the grid-to-plate capacitance of V3 (C_{gp}), and the grid-to-cathode capacitance of V3 (C_{gk}). The combined capacitance (sum) of all of the above capacitances forms a total equivalent shunt capacitance (C_{sh}) that is indicated by the large dashed capacitor in diagram 148.

e. C_{sh} is always present but at low frequencies; and in the midfrequency range, the reactance of C_{sh} is so high that its effect on the circuit is negligible. As the frequency of the signal increases, however, the reactance of C_{sh} decreases; and when the frequency of the signal becomes high enough for the reactance of C_{sh} to fall to a value equal to the resistive load, the output signal voltage of V2 will have decreased to 70.7 percent of the maximum output in the midfrequency range. The decrease in signal voltage is caused by the increased load on V2 which causes the output signal voltage to decrease.

f. At high frequencies the reactance of the coupling capacitor C3 is so low that the ac signal is passed without hindrance; but when the frequency of the signal decreases, the reactance of C3 increases.

g. When the frequency of the signal becomes low enough so that the reactance of C3 is equal to R_g (60,000 ohms), the low-frequency cutoff point is reached. At the low-frequency cutoff point, some of the signal voltage is dropped across C3 which reduces the voltage across R_g. The voltage which appears across R_g is the input signal of V3.

h. Summarizing: The reduction of gain at high frequencies is caused by shunt capacitance, and the reduction in gain at low frequencies is caused by the coupling capacitor C3.

SUMMARY:

1. An RC-coupled amplifier can be designed to provide a good frequency response for almost any desired range.

   a. For instance, such an amplifier can be built to provide a fairly uniform amplification of frequencies in the audio range of about 100 to 20,000 cycles.

   b. Changes in the values of the coupling capacitors and load resistors can extend this frequency range to cover the very wide range required for video service.

2. However, extension of the range can only be obtained at the cost of reduced over-all gain. Thus, the RC method of coupling allows good frequency response with minimum distortion but low amplification.

3. Phase distortion is less with RC coupling than with other types except direct coupling.

LESSON PLAN

BIASING

OBJECTIVE:

To explain and demonstrate:

a. The meaning of the term "bias" as applied to vacuum-tube amplifiers, and

b. The methods of developing bias for amplifiers.

INTRODUCTION:

1. The bias of an amplifier is always the average voltage on the grid with respect to the cathode, regardless of the voltage on those electrodes with respect to any other part of the amplifier circuit.

2. The bias on the grid of an amplifier is normally negative, and it may always be considered as negative unless there is a definite indication that a positive bias is present.

3. There are three methods of producing bias on an amplifier:

   a. Cathode bias (sometimes called self-bias),

   b. Grid-leak bias, and

   c. Fixed bias.

4. The bias on an amplifier may be produced by any one of the three methods listed above or by any combination of the three.

PRESENTATION:

1. **Fixed-bias voltage is obtained from a voltage source which is independent of the signal amplitude or the amount of current (if any) flowing through the amplifier tube. Diagram 150 shows three amplifier circuits, each using a different method of fixed biasing.**

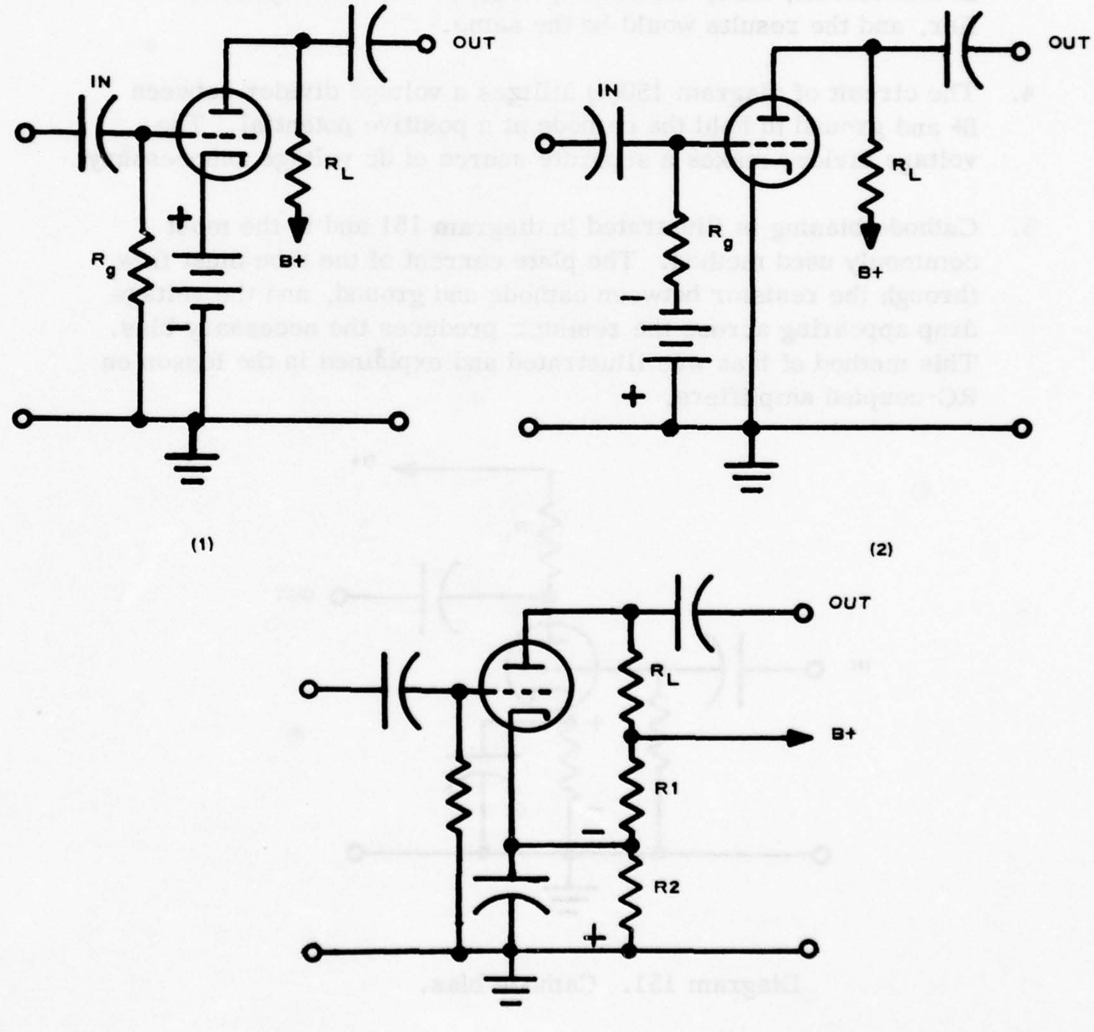

Diagram 150. Fixed bias methods.

2. In diagram 150(1), a battery is used to hold the cathode at a positive potential with respect to ground and grid. The battery could be replaced by a rectifier, and the results would be the same.

3. The battery in diagram 150(2) is connected to hold the grid at a negative potential with respect to ground and cathode. In this circuit, also, the battery could be replaced by a rectifier, and the results would be the same.

4. The circuit of diagram 150(3) utilizes a voltage divider between B+ and ground to hold the cathode at a positive potential. The voltage divider makes a separate source of dc voltage unnecessary.

5. Cathode biasing is illustrated in diagram 151 and is the most commonly used method. The plate current of the tube must flow through the resistor between cathode and ground, and the voltage drop appearing across the resistor produces the necessary bias. This method of bias was illustrated and explained in the lesson on RC-coupled amplifiers.

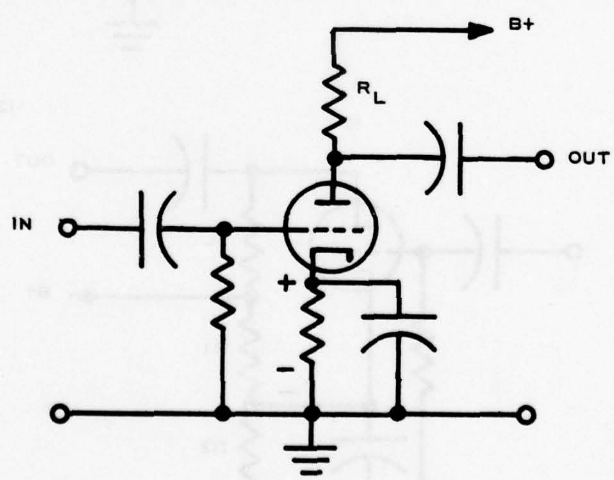

Diagram 151. Cathode bias.

6. Grid-leak bias is produced by the circuit shown in diagram 152.

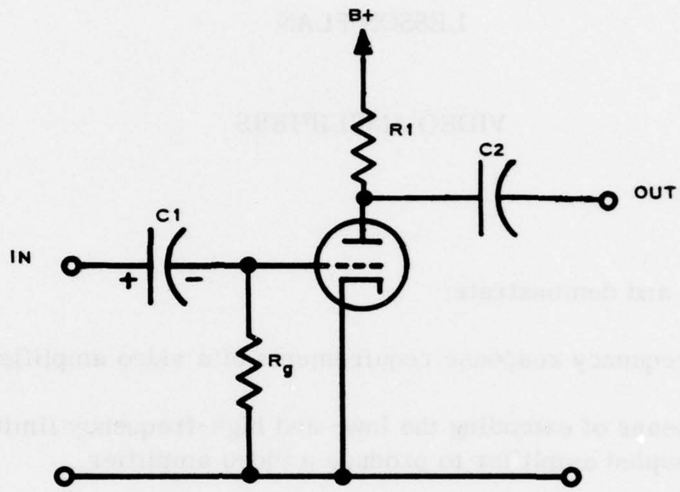

Diagram 152. Grid-leak bias.

a. In the above circuit, bias is obtained when grid current flows through R_g.

b. The tube is biased only when an excitation (input signal) is applied to the circuit since the voltage drop across the resistor depends on grid current.

c. This circuit, therefore, has zero bias if no input signal is present.

<u>SUMMARY</u>:

1. The difference of potential between grid and cathode is called the grid bias of a vacuum tube.

2. There are three general methods of providing this bias voltage. In each of these methods the purpose is to establish the grid at a potential with respect to the cathode which will place the tube in the desired operating condition as determined by its characteristics.

LESSON PLAN

VIDEO AMPLIFIERS

OBJECTIVE:

To explain and demonstrate:

1. The frequency response requirements of a video amplifier, and

2. The means of extending the low- and high-frequency limits of the RC-coupled amplifier to produce a video amplifier.

INTRODUCTION:

1. The term video comes from a Latin word which means "I see." Applied to amplifiers, the term video refers to the ability of an amplifier to amplify pulses or waveforms which may then be used to produce images on a cathode-ray tube.

2. Video amplifiers must be able to amplify without distortion a much wider range of frequencies than the simple, RC-coupled amplifier.

3. The basic amplifier is the RC-coupled amplifier, but the conversion to a video amplifier necessitates an extension of the high-frequency response to about 4 megacycles per second, and the low-frequency response must be lowered to approximately 10 cycles per second.

PRESENTATION:

1. Not only must efficient video amplifiers be able to amplify low frequencies; but also they must be able to amplify harmonics of the low frequencies.

2. A harmonic is a whole-number multiple of a fundamental frequency.

3. Sine waves of voltage contain no harmonics, but nonsinusoidal waveforms are composed of a fundamental frequency and many harmonic frequencies of the fundamental.

4. The square wave shown in diagram 153 is composed of a fundamental frequency of 500 cycles per second and many odd harmonics (1,500 cps, 2,500 cps, 3,500 cps, 4,500 cps, etc.) of the fundamental. An odd harmonic is the fundamental multiplied by 3, 5, 7, etc.

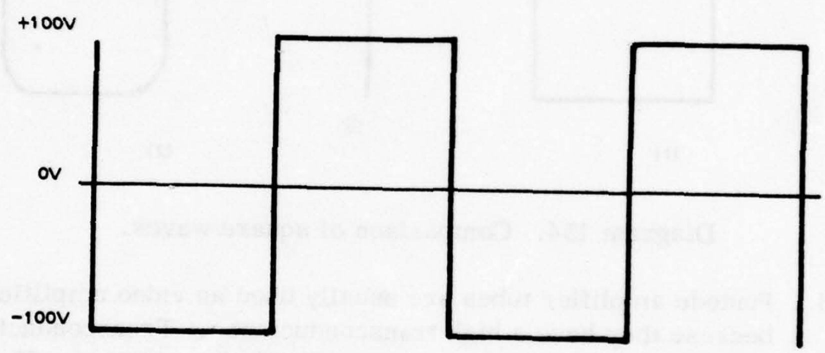

Diagram 153. 500-cps square wave.

5. If a vacuum-tube amplifier is to amplify a square wave with minimum distortion, the low-frequency cutoff point should be below the fundamental frequency of the square wave, and the high-frequency cutoff point should be above the 21st harmonic of the fundamental.

6. As an example, to amplify a 10,000-cps square wave, an amplifier should amplify with minimum distortion (minimum change of waveshape) a frequency range from 10,000 cps (fundamental) to 210,000 cps (21st harmonic).

7. Diagram 154 shows two square waves. An amplifier which has excellent high-frequency response would produce a square wave as shown in diagram 154(1), but an amplifier with insufficient high-frequency response would round off the vertical sides of the square wave as shown in diagram 154(2).

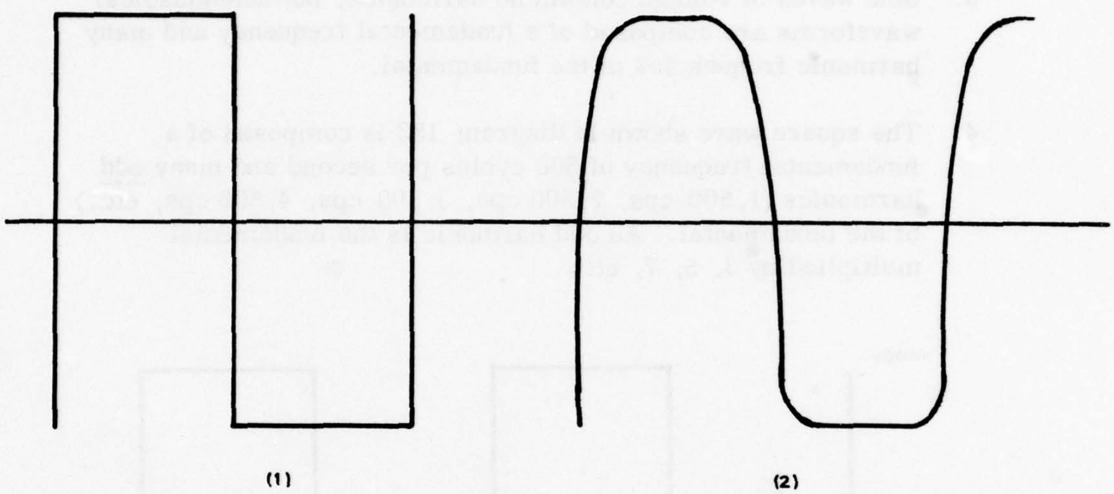

Diagram 154. Comparison of square waves.

8. Pentode amplifier tubes are usually used as video amplifiers because they have a high transconductance. Transconductance is the ability of the grid voltage to control plate current. The greater the transconductance of a tube, the greater the plate current change when the grid changes by one volt.

9. A pentode video-amplifier is shown schematically in diagram 155. V2 with its coupling circuit to the grid of V3 constitutes the video stage to be described below.

10. Three methods of high-frequency compensation are generally used:

    a. Reduction of the plate-load resistor (R_L),

    b. Series-inductance compensation, and

    c. Parallel-inductance compensation.

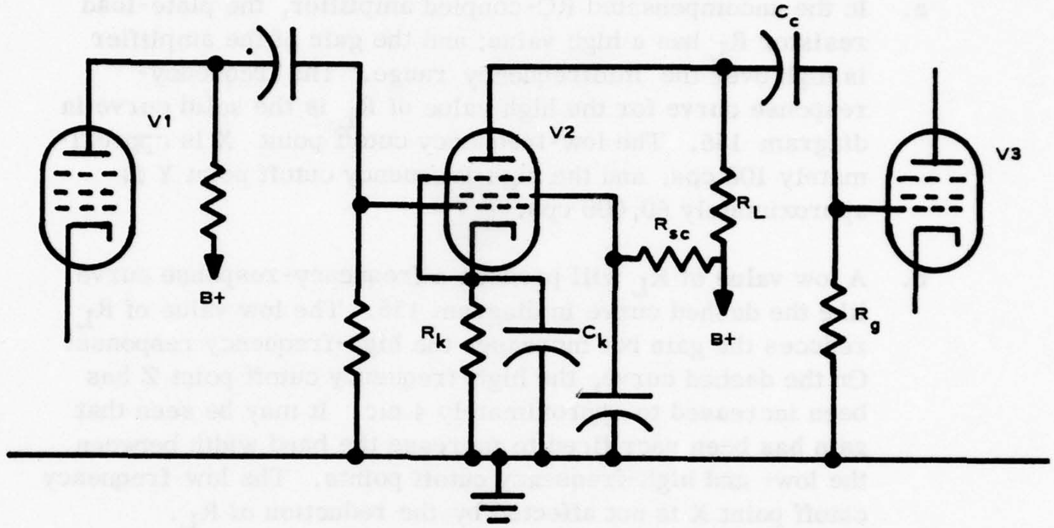

Diagram 155. Pentode video-amplifier.

11. Reducing the plate-load resistor R_L to a relatively low value is the first and most important means of increasing the high-frequency response of any video amplifier. This compensation is always used, and its effects are illustrated in diagram 156. The following statements refer to R_L in diagram 155 and to the frequency-response curves of diagram 156.

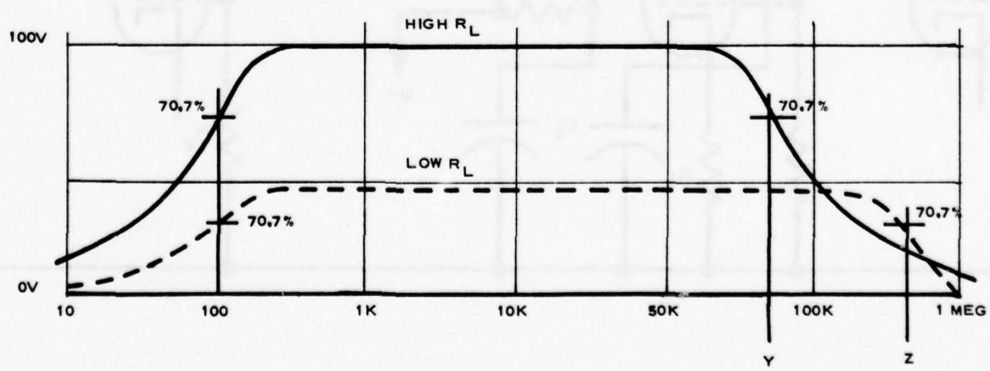

Diagram 156. Frequency-response curves.

a. In the uncompensated RC-coupled amplifier, the plate-load resistor R_L has a high value; and the gain of the amplifier is high over the midfrequency range. The frequency-response curve for the high value of R_L is the solid curve in diagram 156. The low-frequency cutoff point X is approximately 100 cps, and the high-frequency cutoff point Y is approximately 60,000 cps.

b. A low value of R_L will produce a frequency-response curve like the dashed curve in diagram 156. The low value of R_L reduces the gain but increases the high-frequency response. On the dashed curve, the high-frequency cutoff point Z has been increased to approximately 4 mc. It may be seen that gain has been sacrificed to increase the band width between the low- and high-frequency cutoff points. The low-frequency cutoff point X is not affected by the reduction of R_L.

12. Series-inductance compensation is illustrated in diagram 157.

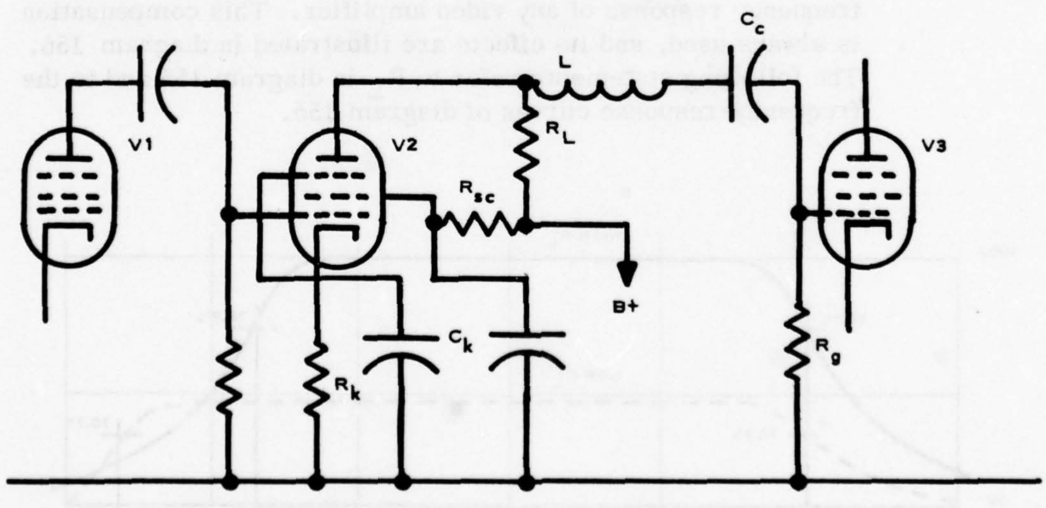

Diagram 157. Series compensation.

a. The inductance L is in series with the signal since the signal must go through the inductance to reach the grid of V3.

b. Without the inductance in the circuit, the frequency response of the circuit is as shown by the solid curve of diagram 158.

c. The series inductance L is of such a value that it resonates in series with the input capacitance of V3 at a frequency somewhat higher than the high-frequency cutoff point for the uncompensated circuit.

d. The effect of the series inductance is to increase the high-frequency response as indicated by the dashed curve in diagram 158. The rise in the dashed curve is not objectionable. The important characteristic shown by the curve is the increase of the high-frequency cutoff point from 400 kc to about 2 mc per second.

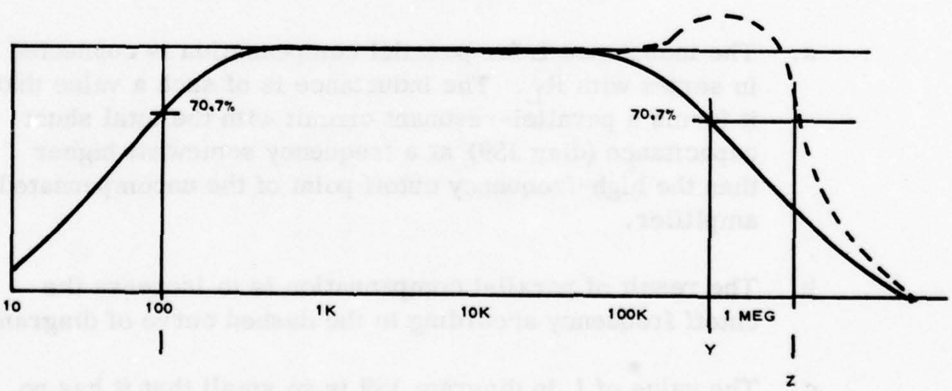

Diagram 158. Effect of series compensation.

e. The value of the inductance is so small that it has negligible effect at the midfrequency range.

13. **Parallel-inductance compensation is illustrated in diagram 159.**

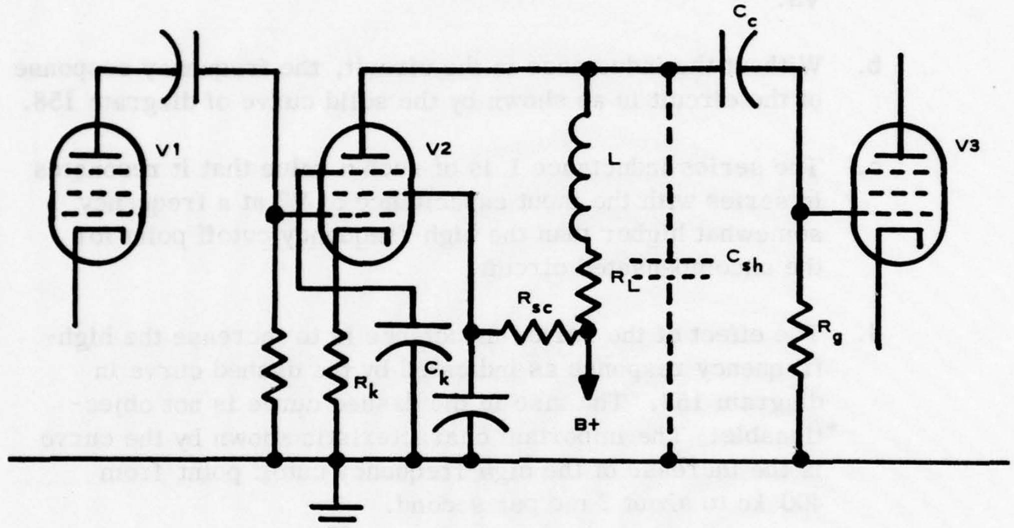

Diagram 159. Parallel compensation.

a. **The inductance L for parallel compensation is c nnected in series with R_L. The inductance is of such a value that it forms a parallel-resonant circuit with the total shunt capacitance (diag 159) at a frequency somewhat higher than the high-frequency cutoff point of the uncompensated amplifier.**

b. **The result of parallel compensation is to increase the cutoff frequency according to the dashed curve of diagram 158.**

c. **The value of L in diagram 159 is so small that it has no effect at the midfrequency range.**

14. **Low-frequency compensation of a video amplifier may be accomplished by the addition of the resistor R_f and the capacitor C_f shown in diagram 160.**

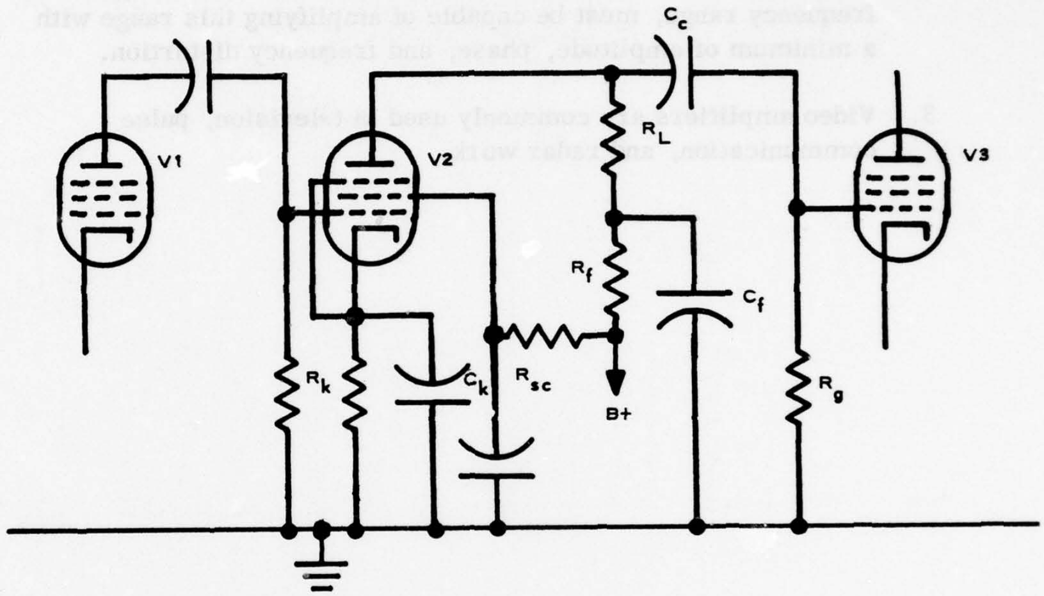

Diagram 160. Low-frequency compensation.

a. The value of C_f is such that $C_f\ R1 = C_c\ R_g$. (55)

b. The value of R_f is such that $10\ R_f = X_{cf}$ at the lowest desired frequency. (56)

15. *In any video amplifier, the reactance in ohms of* C_k should never be more than one-tenth the resistance of R_k at the lowest frequency at which the amplifier must operate.

SUMMARY:

1. A video frequency amplifier is one which has been designed to pass frequencies from the lower audio range (approximately 50 cycles) to the middle rf range (approximately 4 to 6 megacycles).

2. Such amplifiers, in addition to passing such an extremely wide frequency range, must be capable of amplifying this range with a minimum of amplitude, phase, and frequency distortion.

3. Video amplifiers are commonly used in television, pulse communication, and radar work.

LESSON PLAN

POWER AMPLIFIERS

OBJECTIVE:

To explain and demonstrate:

1. The differences between voltage amplifiers and power amplifiers,
2. The necessity for power amplifiers,
3. The classes of operation according to bias, and
4. The efficiency to be expected in power amplifiers.

INTRODUCTION:

1. There are two general classifications into which vacuum-tube amplifiers fall: voltage amplifiers and power amplifiers.
2. Voltage amplifiers are designed to produce as much signal voltage gain as possible from input to output regardless of the amplifier efficiency.
3. Power amplifiers must produce as much ac power output as possible regardless of the voltage gain involved.
4. An example of the use of voltage amplifiers and power amplifiers is found in a radio receiver designed to receive commercial broadcast signals.
   a. All amplifiers in the receiver with the exception of one are voltage amplifiers. The last amplifier in the receiver is a power amplifier.
   b. The signal received by the antenna generally has an amplitude of a few microvolts. The amplitude of the signal voltage

must be increased several thousand times before it becomes great enough to do an appreciable amount of work. Voltage amplifiers are necessary to increase the signal amplitude; and the greater the voltage gain in each tube, the fewer tubes are necessary.

c. The last tube in the receiver must supply a fairly large amount of power to the speaker; and the tube, with its associated coupling circuit, must be designed as a power amplifier.

PRESENTATION:

1. The amplifier tube may be thought of as equivalent to an ac generator that has a relatively high internal resistance.

2. Diagram 161 shows the equivalent generator with its internal resistance indicated as 5,000 ohms.

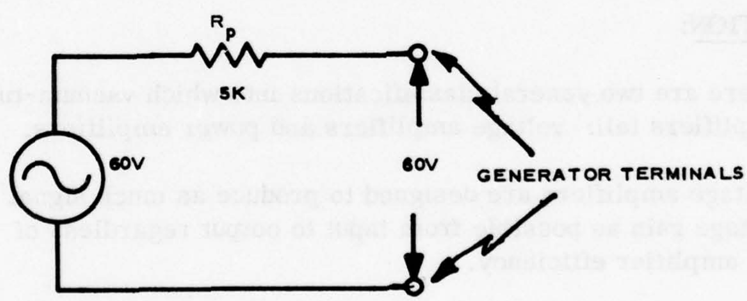

Diagram 161. Equivalent generator.

a. The internal resistance, shown as part of the equivalent generator circuit, corresponds to the internal (plate) resistance of the amplifier tube. The plate-load resistor of a vacuum-tube amplifier, across which the output signal voltage is developed, corresponds to the resistive load of the generator. Diagram 162 illustrates the equivalent generator of diagram 161 with the plate-load resistor connected to its output terminals.

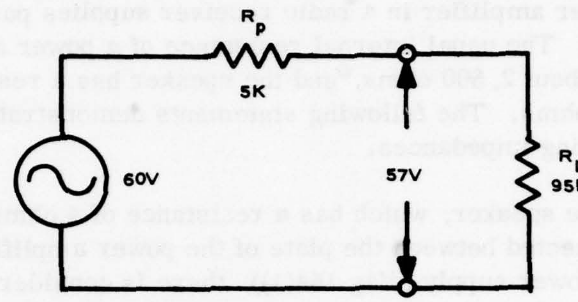

Diagram 162. Loaded generator.

b. If the generator is a voltage amplifier, the load resistor is made as large as practicable so that the voltage across R_L is a large percentage of the generator voltage.

c. If the generator is a power amplifier, the load resistance is made equal to the internal resistance of the generator. Maximum power is delivered to the load only when the load is equal to the internal resistance of the generator as shown in diagram 163. When the load resistance is equal to the internal resistance of the tube, there exists an impedance match between the load and the tube.

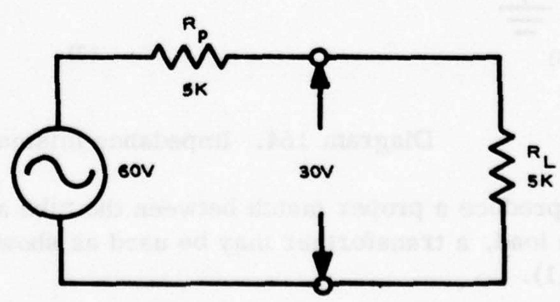

Diagram 163. Matched impedances.

3. The power amplifier in a radio receiver supplies power to the speaker. The usual internal resistance of a power amplifier tube is about 2, 500 ohms, and the speaker has a resistance of about 4 ohms. The following statements demonstrate the method of matching impedances.

   a. If the speaker, which has a resistance of 4 ohms, is connected between the plate of the power amplifier and the dc power supply (diag 164(1)), there is considerable mismatch between the 4-ohm speaker and the 2, 500-ohm internal resistance of the tube (diag 164(2)), and only a small amount of the output power of the tube is supplied to the speaker.

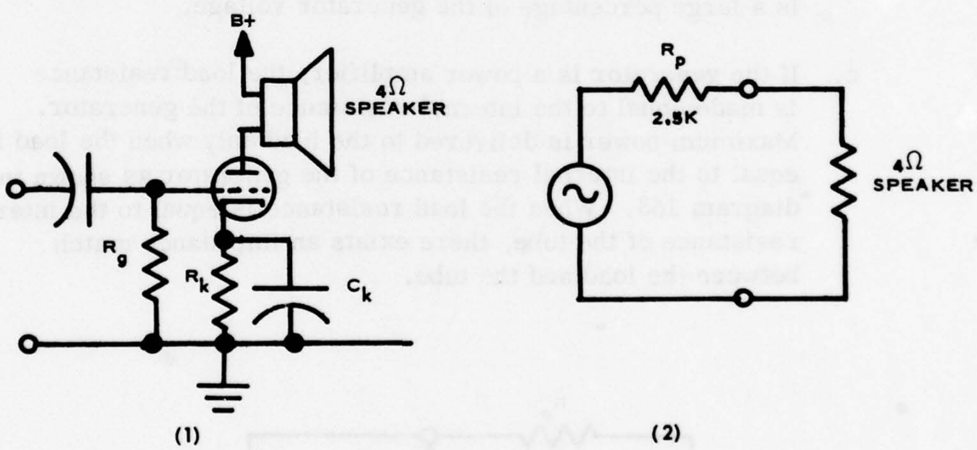

Diagram 164. Impedance mismatch.

   b. To produce a proper match between the tube and the four-ohm load, a transformer may be used as shown in diagram 165(1).

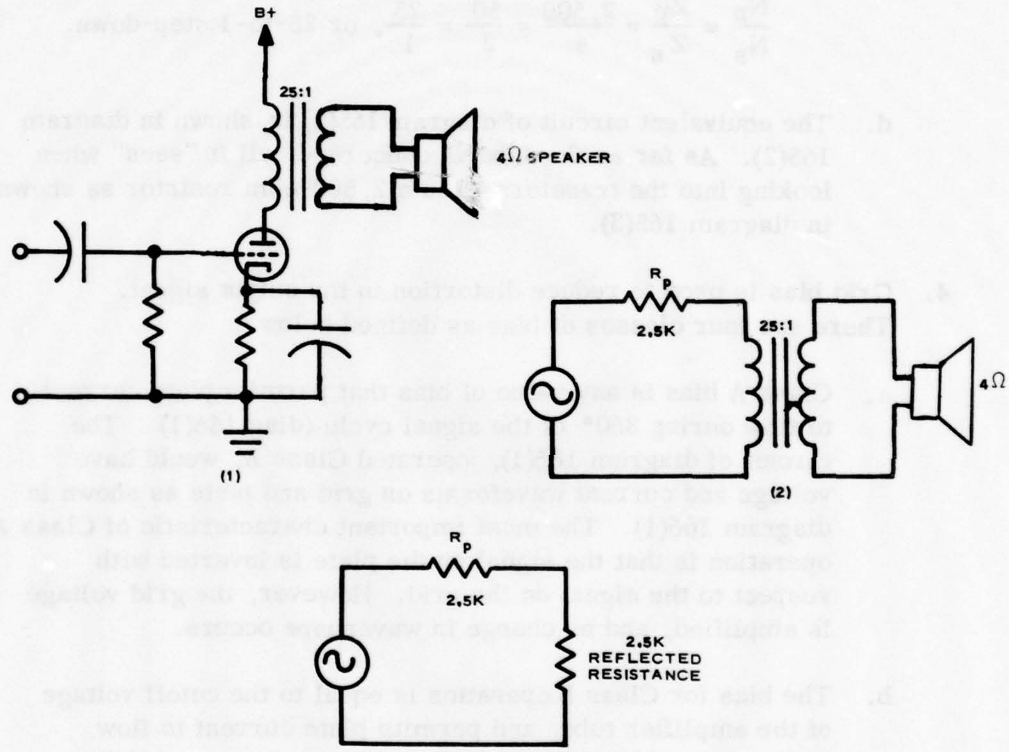

Diagram 165. Impedance-matching transformer.

c. **Since the tube requires a resistive load of 2,500 ohms for maximum power transfer to the load, the transformer**

must have the proper turns ratio to cause the 4-ohm load to be reflected into the primary as 2,500 ohms. The turns ratio is found by equation (48):

$$\frac{N_p}{N_s} = \frac{Z_p}{Z_s} = \frac{2,500}{4} = \frac{50}{2} = \frac{25}{1}, \text{ or 25-to-1 step-down.}$$

d. The equivalent circuit of diagram 165(1) is shown in diagram 165(2). As far as the tube is concerned, all it "sees" when looking into the transformer is a 2,500-ohm resistor as shown in diagram 165(3).

4. Grid bias is used to reduce distortion in the output signal. There are four classes of bias as defined below.

a. Class A bias is any value of bias that permits plate current to flow during 360° of the signal cycle (diag 166(1) . The circuit of diagram 165(1), operated Class A, would have voltage and current waveforms on grid and plate as shown in diagram 166(1). The most important characteristic of Class A operation is that the signal on the plate is inverted with respect to the signal on the grid. However, the grid voltage is amplified, and no change in waveshape occurs.

b. The bias for Class B operation is equal to the cutoff voltage of the amplifier tube, and permits plate current to flow during only 180° of the signal cycle. In diagram 166(2) it may be seen that only during the positive half-cycles of the input signal does the grid permit plate current to flow. The negative half-cycles drive the grid below cutoff, and the plate voltage is constant at B+ potential. The plate voltage goes through a negative half-cycle corresponding to the positive half-cycle of the input signal, but the positive half-cycle on the plate is absent because plate current is zero.

c. The circuit of diagram 165(1) should not operate with Class B bias because the signal waveforms appearing at the plate are greatly distorted.

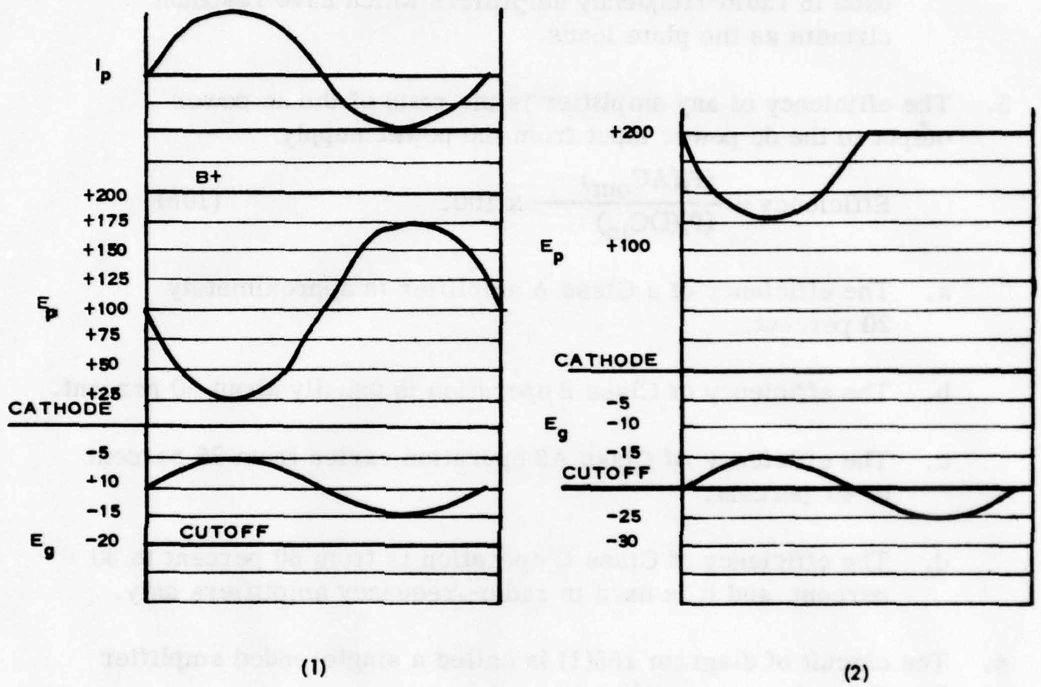

Diagram 166. Class A and Class B bias.

d. Class AB bias is less negative than Class B bias, but it is not low enough to to permit plate current to flow during the whole signal cycle. Class AB bias may be defined as that value of bias which permits plate current to flow more than 180°, but less than 360° of the signal cycle.

e. If the circuit of diagram 165(1) were operated with Class AB bias, the output would be distorted and would not be satisfactory as an audio-frequency amplifier.

f. Class C bias is much greater than the cutoff voltage of the tube. It may be defined as a bias that permits current to flow less than 180° of the signal cycle. Class C bias is

never used for audio-frequency amplifiers; it is, however, used in radio-frequency amplifiers which have resonant circuits as the plate loads.

5. The efficiency of any amplifier is the ratio of the ac power output to the dc power input from the power supply:

$$\text{Efficiency} = \frac{(P)(AC_{out})}{(P)(DC_{in})} \times 100. \qquad (106)$$

   a. The efficiency of a Class A amplifier is approximately 20 percent.

   b. The efficiency of Class B operation is usually about 50 percent.

   c. The efficiency of Class AB operation varies from 25 percent to 40 percent.

   d. The efficiency of Class C operation is from 60 percent to 80 percent, and it is used in radio-frequency amplifiers only.

6. The circuit of diagram 165(1) is called a single-ended amplifier because only one amplifier is used.

7. Diagram 167 shows a push-pull amplifier which uses two tubes in an arrangement that permits one tube to produce an output that is 180° out of phase with the output of the other tube.

   a. The arrows on all waveforms indicate the same instant of time.

   b. Tube V1 is the amplifier of the preceding stage, and its output is a sine wave.

   c. The transformer T1 has a center-tapped secondary that is grounded. The two ends of the secondary produce signal voltages that are 180° out of phase with one another with respect to ground. The two signal voltages from T1 are referred to as push-pull voltages.

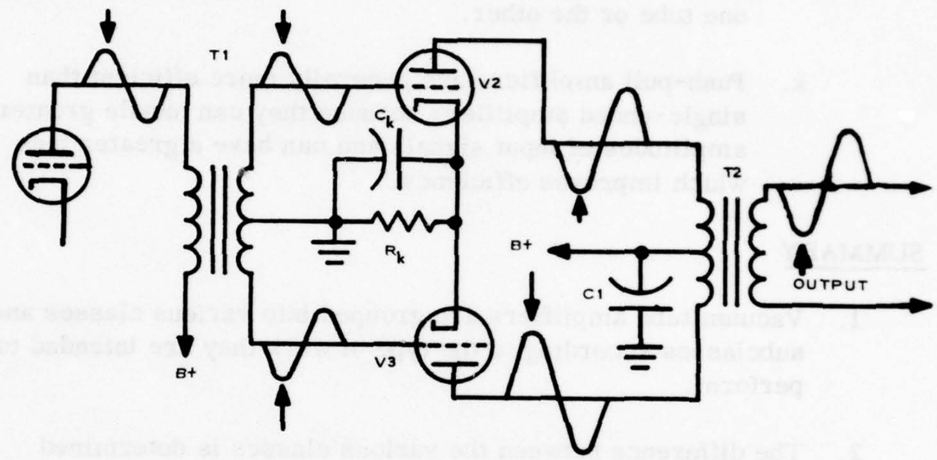

Diagram 167. Push-pull amplifier.

d. V2 and V3 receive the push-pull signals on their respective grids and produce amplified signals on their plates which are also 180° out of phase with one another.

e. The push-pull voltages developed on the plates of V2 and V3 are applied to opposite ends of the output transformer, T2.

f. The primary of T2 is grounded for ac by the capacitor C1.

g. The two input voltages on the primary of T2 produce a single sine wave of voltage on the secondary of T2.

h. Tubes V2 and V3 may be operated Class A, Class AB, or Class B without producing objectionable distortion in the output.

i. All single-ended amplifiers, such as shown in diagram 165(1), tend to produce second-harmonic distortion in the output. Second-harmonic distortion cancels out in the plate circuit of push-pull amplifiers.

j. Push-pull amplifiers may operate Class AB or Class B because the output waveform is always under control of one tube or the other.

k. Push-pull amplifiers are generally more efficient than single-ended amplifiers because they can handle greater amplitudes of input signals and can have a greater bias which improves efficiency.

SUMMARY:

1. Vacuum tube amplifiers are grouped into various classes and subclasses according to the type of work they are intended to perform.

2. The difference between the various classes is determined primarily by the value of average grid bias employed and the maximum value of the exciting signal to be impressed upon the grid.

3. The efficiency of a vacuum tube increases as the tube is driven closer to saturation.

LESSON PLAN

CATHODE FOLLOWERS

OBJECTIVE:

To explain and demonstrate:

1. The characteristics of cathode followers that make them important in electronics,

2. Applications of cathode followers, and

3. Frequency response of cathode followers.

INTRODUCTION:

1. A cathode follower is a single-stage, degenerative amplifier in which the output is taken across the cathode resistor.

2. Cathode followers are commonly referred to as impedance-matching devices, but they do not match impedances in the same way that a transformer does. Cathode followers have a very high, input impedance (low, input capacitance), and relatively low, internal resistance.

3. These characteristics of high input impedance and low output resistance make them useful for certain applications.

4. The output signal voltage of a cathode follower is always less in amplitude than the input signal voltage. In other words, the cathode follower is an amplifier with a gain of less than one.

5. The output signal voltage of a cathode follower is always in phase with or "follows" the input signal voltage (hence, the name "cathode follower") as contrasted with a conventional tube amplifier in which the output voltage is 180° out of phase with the input voltage.

6. The high-frequency response of a cathode follower is much better than that of the RC-coupled amplifier. Therefore, it is an excellent video amplifier because it does not need the usual high-frequency compensations that are so necessary in the RC-coupled video amplifier.

PRESENTATION:

1. The theoretical maximum gain of a triode is called the amplification factor, and the symbol for "amplification factor" is the Greek letter μ (mu). The tube manufacturer gives the amplification factor for 6J5 triode as 20.

2. Another characteristic of a triode is the ac plate resistance R_p which for a 6J5 is given by the manufacturer as 6, 700 ohms.

3. When the 6J5 is used as shown in diagram 168(1), the equivalent generator circuit is as shown in diagram 168(2). The following statements apply to diagram 168.

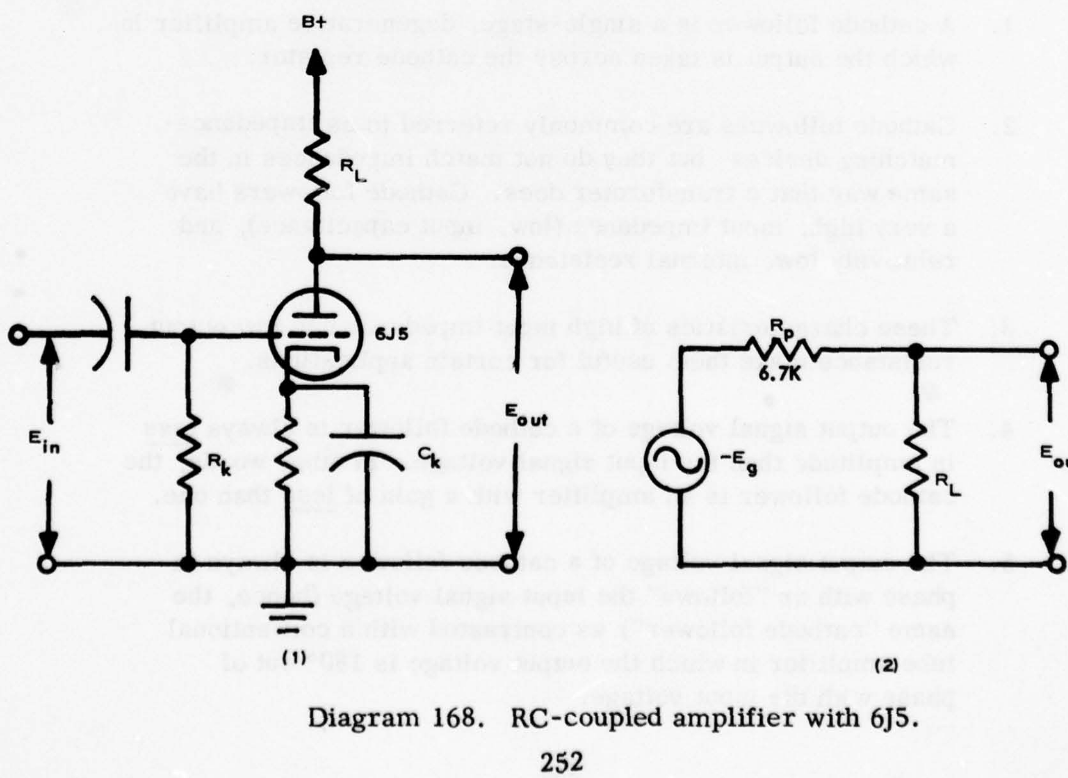

Diagram 168. RC-coupled amplifier with 6J5.

a. The output signal voltage of the equivalent generator is equal to the input signal voltage multiplied by the amplification factor. The ac plate resistance (6, 700 ohms in diagram 168(2) causes the voltage drop which prevents the output across R_L from being equal to $(\mu)(E_g)$.

b. Any load connected to the amplifier will appear in the equivalent circuit of diagram 168(2) as connected in parallel with R_L. The additional load causes an increase in current through R_p which, in turn, causes the output voltage to decrease because of the increased voltage drop in R_p.

5. When a 6J5 tube is connected as a cathode follower, as shown in diagram 169(1), the equivalent circuit becomes that shown in diagram 169(2).

a. The voltage developed in the equivalent generator (diag 169(2)) is always less than the input signal voltage. The generator voltage is equal to the input signal voltage E_g multiplied by $\frac{\mu}{\mu + 1}$ which gives a generator voltage of 95.2 percent of the signal voltage in the 6J5 tube.

b. The internal resistance of the equivalent generator is much less than the ac plate resistance of the tube. As shown in diagram 169(2), the internal resistance is equal to the normal ac plate resistance (6, 700 ohms in the 6J5) divided by μ plus 1 $(\mu + 1)$.

$$R = \frac{R_p}{\mu + 1} \tag{58}$$

In the circuit of diagram 169(2), the internal resistance is 319 ohms.

c. Since the internal resistance of the generator is very low, the tube can supply a rather high current to the load. Even though the output signal voltage of the cathode follower is low, the high current that can be supplied makes possible a rather high power output.

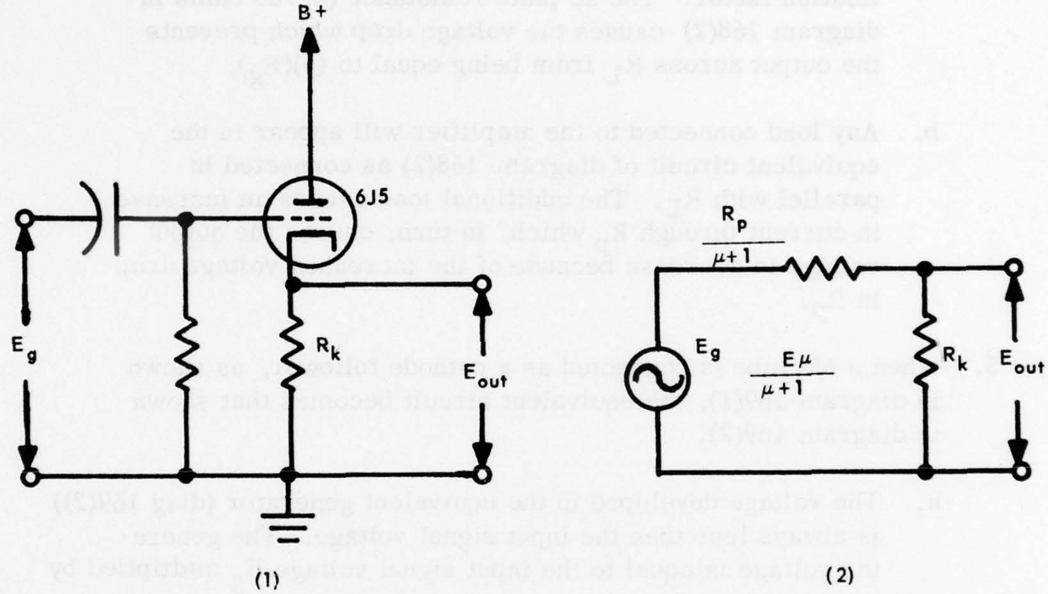

Diagram 169. Cathode follower.

d. The ac signal that appears across the cathode resistor R_k is the output signal. Any load connected to the cathode follower is connected in parallel with the cathode resistor R_k.

6. Any amplifier is a degenerative amplifier if the ac component of current flow in the plate circuit causes a reduction of the effective ac signal input between the grid and cathode.

7. Cathode followers are degenerative amplifiers because the effective signal input between the grid and cathode is equal to the signal voltage supplied at the input terminals minus the signal appearing on the cathode (diag 170).

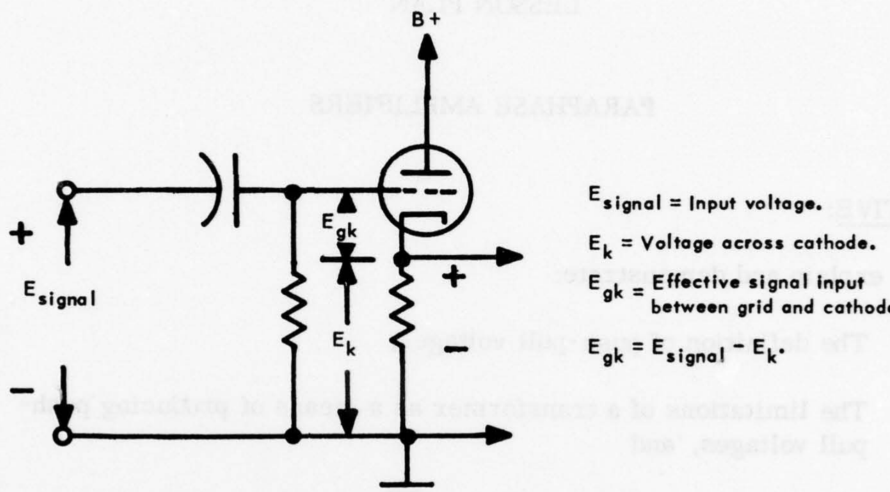

Diagram 170. Degenerative action of cathode follower.

8. The very high input impedance (very small capacitance between grid, plate, and cathode) makes the cathode follower very useful as the first amplifier stage in test oscilloscopes. The high input impedance makes it possible to observe waveforms in circuits which cannot supply an appreciable current for test purposes.

9. The very low output impedance of the cathode follower (low internal resistance) is utilized in supplying signals to low impedance loads because the tube can supply high current without an appreciable drop in output voltage.

SUMMARY:

The gain of a cathode follower is always less than unity. Its use is usually limited to situations:

1. Where it is desired to match a high impedance source to a low impedance load, or
2. Where it is desired to feed a load of varying impedance with a signal having good regulation.

IF-31

LESSON PLAN

PARAPHASE AMPLIFIERS

OBJECTIVE:

To explain and demonstrate:

1. The definition of push-pull voltages,

2. The limitations of a transformer as a means of producing push-pull voltages, and

3. Two vacuum-tube circuits used to produce push-pull voltages from a single signal input.

INTRODUCTION:

A paraphase amplifier is a vacuum-tube circuit which develops two ac output voltages of equal amplitudes and opposite polarity from a single input signal.

> INSTRUCTOR'S NOTE: Use the demonstration board for paraphase amplifiers to demonstrate the amplifier in this lesson.

PRESENTATION:

1. A transformer with a center-tapped secondary may be used to produce push-pull voltages from a single signal as shown in diagram 171.

   a. The greatest advantage of a transformer as a means of developing push-pull voltages is the simplicity with which output voltages that may be greater or less in amplitude than the input signal depending on the turns ratio between primary and secondary are produced.

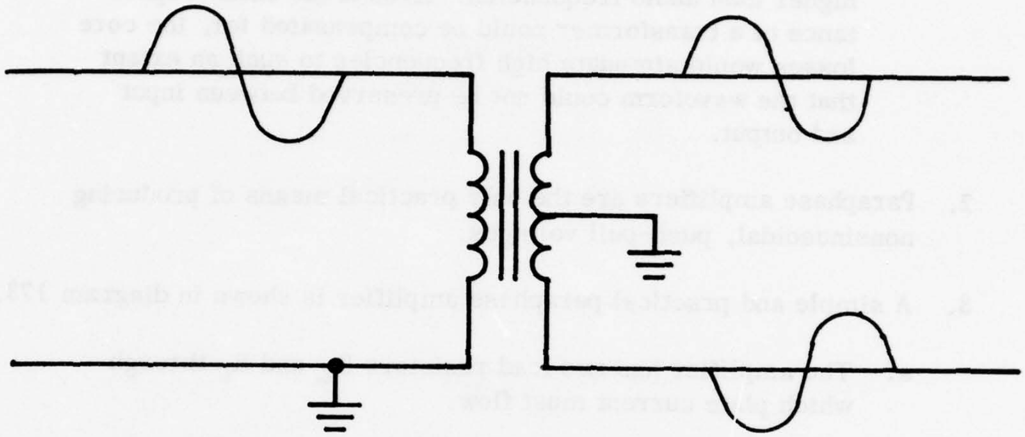

Diagram 171. Transformer with push-pull output.

b. Transformers are frequently used to develop push-pull voltages for audio-frequency amplifiers, but they are not satisfactory when the signals are nonsinusoidal.

c. Nonsinusoidal waveforms, such as sawtoothed, trapezoidal, and square waves contain very high frequency components which, if eliminated, would change the waveshape (diag 172).

Diagram 172. Nonsinusoidal waveforms.

d. Transformers whose windings are wound on iron cores have relatively high shunt capacitance to the core, and normally will not function efficiently at frequencies much

higher than audio frequencies. Even if the shunt capacitance of a transformer could be compensated for, the core losses would attenuate high frequencies to such an extent that the waveform could not be preserved between input and output.

2. Paraphase amplifiers are the only practical means of producing nonsinusoidal, push-pull voltages.

3. A simple and practical paraphase amplifier is shown in diagram 173.

   a. The amplifier has two load resistors R_L and R_k through which plate current must flow.

   b. The same current must flow through R_L and R_k, and since the two resistors have the same value, the same voltage drop appears across each resistor.

   c. The sawtoothed signal on the grid produces a sawtoothed signal on the cathode (by cathode-follower action), and there is no inversion of the signal between grid and cathode. In the lesson on cathode followers, it was shown that the signal on the cathode was always <u>lower</u> in amplitude than the input signal on the grid; therefore, the signal at output terminal Y is less than the input signal.

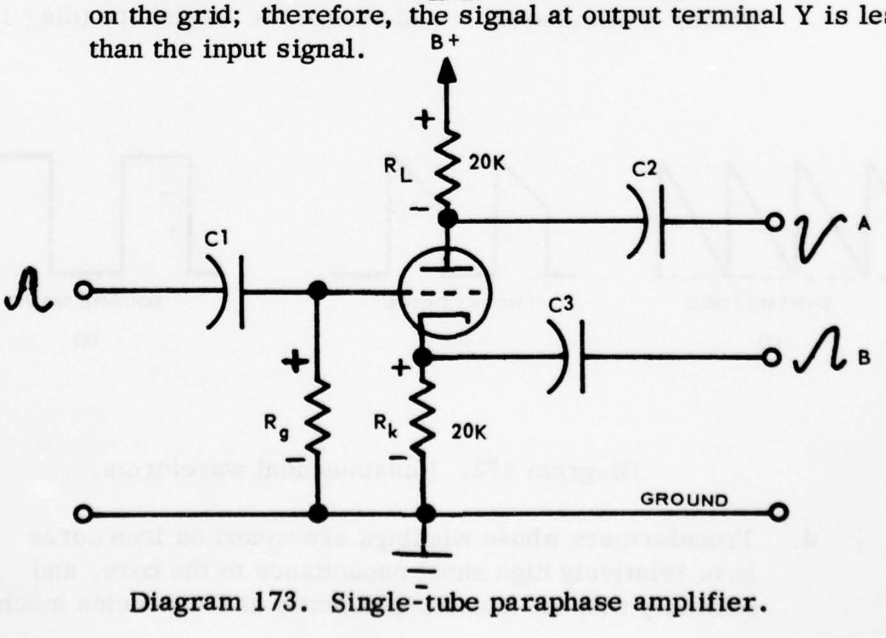

Diagram 173. Single-tube paraphase amplifier.

d. Considering the input to the grid and output from the plate, the amplifier tube is an RC-coupled amplifier. In the lesson on RC-coupled amplifiers, it was learned that there is always an *inversion of the signal between the grid* and the plate; therefore, the signal at output terminal X will be inverted with respect to the input on the grid.

e. The ac signal developed across R_L is produced by the same current that produced the ac signal across R_k; and since R_L R_k have the same value, the two signals will have the same amplitude, but each will be the inversion of the other.

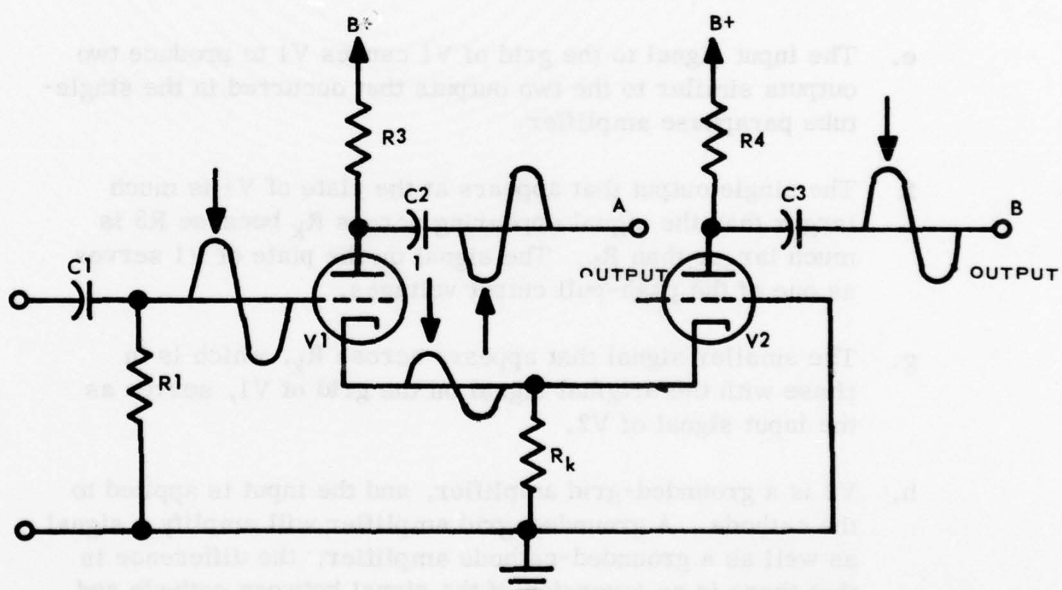

Diagram 174. Cathode-coupled paraphase amplifier.

f. The single-tube, paraphase amplifier has the advantage of simplicity and the additional advantage that the two outputs will remain balanced (equal amplitudes), even though the gain of the tube decreases as it ages. It has the disadvantage of having no gain in amplitude between input and either output.

4. The disadvantage of lack of amplification in the single-tube paraphase amplifier is overcome in the cathode-coupled, paraphase amplifier shown in diagram 174.

a. C1 and R1 make up an RC-coupling circuit that conveys the input signal to the grid of V1.

b. R_k provides a common path from ground to the cathodes of both V1 and V2.

c. The push-pull output voltages appear at output terminals X and Y.

d. The waveforms that appear at several points in the circuit are shown, and the arrows on each waveform indicate the same instant of time.

e. The input signal to the grid of V1 causes V1 to produce two outputs similar to the two outputs that occurred in the single-tube paraphase amplifier.

f. The single output that appears at the plate of V1 is much larger than the signal appearing across R_k because R3 is much larger than R_k. The signal on the plate of V1 serves as one of the push-pull output voltages.

g. The smaller signal that appears across R_k, which is in phase with the original signal on the grid of V1, serves as the input signal of V2.

h. V2 is a grounded-grid amplifier, and the input is applied to the cathode. A grounded-grid amplifier will amplify a signal as well as a grounded-cathode amplifier; the difference is that there is no inversion of the signal between cathode and plate.

i. The signal appearing on the plate of V2 serves as the second push-pull output voltage.

<u>SUMMARY:</u>

1. The paraphase amplifier is used whenever it is necessary to furnish two identical waveforms that are alike in all respects but separated by a 180° phase difference. It is for this reason that they are often used in driving a push-pull output stage.

2. **A paraphase amplifier can usually be identified by the cathode and plate load resistors of the same value.**

LESSON PLAN

DETECTORS

OBJECTIVE:

To explain and demonstrate:

1. The necessity for a detector in a radio receiver,
2. The essential processes necessary for the demodulation of an amplitude-modulated radio signal,
3. The characteristics of a good detector, and
4. The functioning of each component in a diode detector.

INTRODUCTION:

One of the methods of transmitting intelligence involves the process of using an af (audio-frequency) signal to vary the amplitude of the rf (radio-frequency) output of a transmitter. This process is called modulation.

The result is a modulated rf wave capable of traveling great distances through space. A receiver situated at a distance from the transmitter picks up the wave and separates the af modulation from the rf carrier.

This process of separating the two components of the received signal is called detection. A detector is a circuit which eliminates the carrier frequency while allowing the audio frequencies to pass with very little distortion. Detection is an integral part of any communication system using carrier frequencies.

PRESENTATION:

1. It was stated that detection is the separation of audio frequencies from a carrier wave. What is desired is a complete re-creation of the modulating wave which will later be used to reproduce the

original sounds. The task indicates certain properties which a detector must possess. If the detected waveform is to be a reproduction of the modulating voltage, the detector must add as little distortion as possible. The concept of fidelity, or linearity of the circuit, is a measure of the detector's ability to faithfully reproduce the af wave.

2. A detector, besides having good fidelity, should attenuate the signal as little as possible; therefore, the sensitivity, or efficiency, of detection is of importance.

3. Another important characteristic is the signal-handling capability of the detector. This characteristic is a measure of the detector's ability to handle strong signals without introducing distortion. Fidelity, sensitivity, and signal-handling capability are usually the characteristics of interest in considering the operation of a detector.

4. Amplitude modulation is accomplished by varying the amplitude of a radio-frequency wave in accordance with the signal generated by a device such as a microphone which transforms sound energy into electrical impulses. An amplitude-modulated wave is shown in diagram 175. This waveform is radiated from the transmitter antenna into surrounding space and is picked up by a receiving antenna. The received waveform retains its original shape, but it is attenuated. The job of the detector in the receiver consists of separating the amplitude variations from the received signal.

5. To separate the intelligence carried by the amplitude variations from the rf signal, some device is necessary which can follow the peak values of the rf waves only. If the amplitude-modulated wave in diagram 175 is rectified, the resulting wave will be as shown in diagram 176. This wave is made up of a constant-amplitude rf carrier with a varying af component superimposed on it. Therefore, the af signal is the intelligence in this case. It is necessary to have a set of circuit elements which will eliminate the alternating rf component but will allow the af component to pass to the output from which point it will be further amplified.

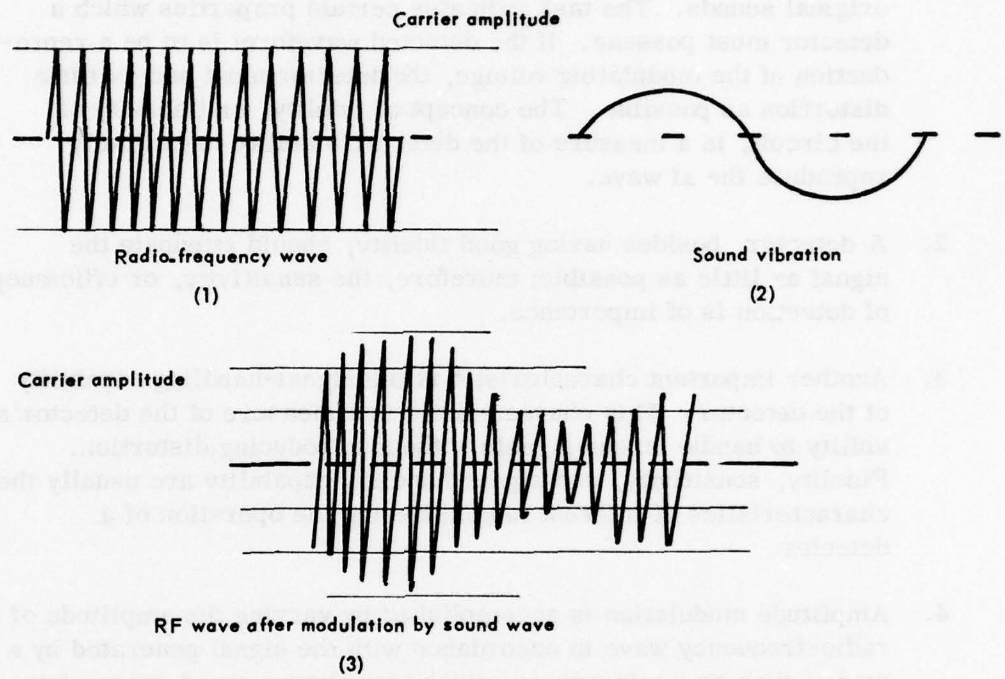

Diagram 175. Amplitude-modulated wave.

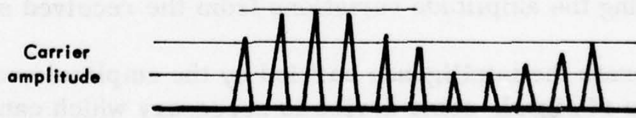

Diagram 176. Rectified rf wave which is amplitude-modulated.

6. The basic arrangement of the diode-detector circuit is shown in diagram 177. This circuit consists of a diode tube connected in series with a parallel RC combination. The input is applied across the series combination of the tube and the RC network, and the output is taken across the RC combination.

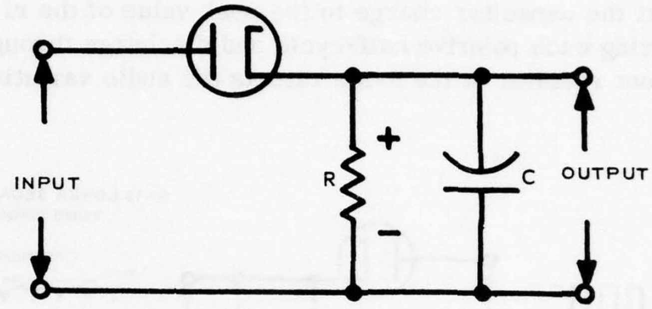

Diagram 177. Basic arrangement of diode detector.

7. The operation of the diode detector shown in diagram 177 is as follows:

   a. When an unmodulated rf signal is applied to the input, the diode will conduct each time its plate swings positive with respect to its cathode. The capacitor will charge rapidly (small time constant) to approximately the peak value of the rf wave because of the small resistance of the diode while it conducts.

   b. As the rf wave starts to go negative, the plate becomes negative with respect to the cathode, and conduction stops. The charged capacitor now starts to discharge through the resistor; however, this resistor is chosen to be many times larger than the conducting resistance of the diode, and the capacitor loses very little charge during the negative half-cycle. Whatever charge is lost is replenished during each successive positive swing.

   c. The output appears as indicated in diagram 178. This output can be seen to be the same as that of a half-wave rectifier with an RC filter. In the detector, however, the additional consideration of following variations in the amplitude of the

input is necessary. What is desired of the RC combination is that the capacitor charge to the peak value of the rf wave during each positive half-cycle and discharge through its shunt resistor at the same rate as the audio variation.

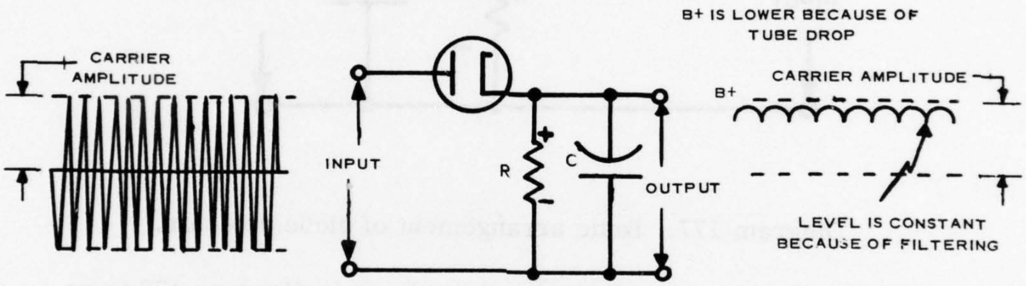

Diagram 178. Basic diode detector indicating output for unmodulated rf input.

d. The ideal output for a modulated rf wave input is shown in diagram 179. This condition, however, is not realizable. A close approximation of the rf envelope can be obtained by a proper choice of the RC time constant.

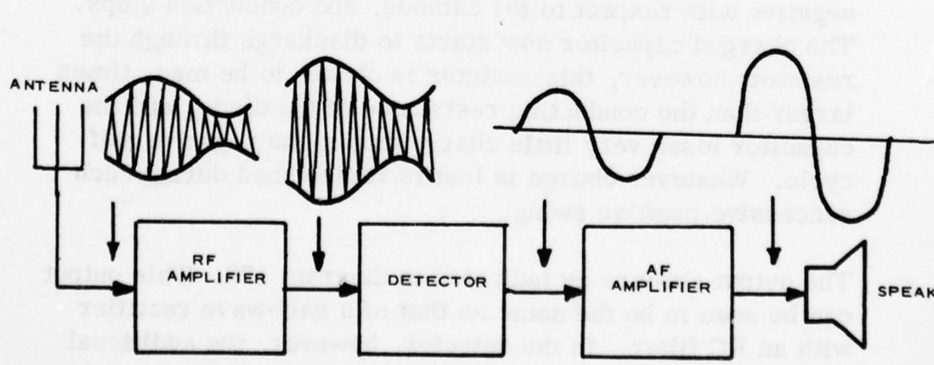

Diagram 179. Basic diode detector indicating ideal output for modulated rf input.

The necessary considerations governing the choice of the RC time constant can be seen from diagram 180. The diagram shows the rf input and resulting output waveforms. The output waveform does not reach the peak values of the input because of the voltage drop across the diode. If the RC time constant is chosen correctly, the charge and discharge curve will be as indicated by the curve labeled "output voltage." However, if the RC time constant is too long, the capacitor will not discharge fast enough to follow the modulation as it goes negative. The resulting output is indicated by the curve labeled "RC Too Long" and is called diagonal clipping. The diagram is greatly exaggerated; there are ordinarily many more cycles of rf for each cycle of the envelope.

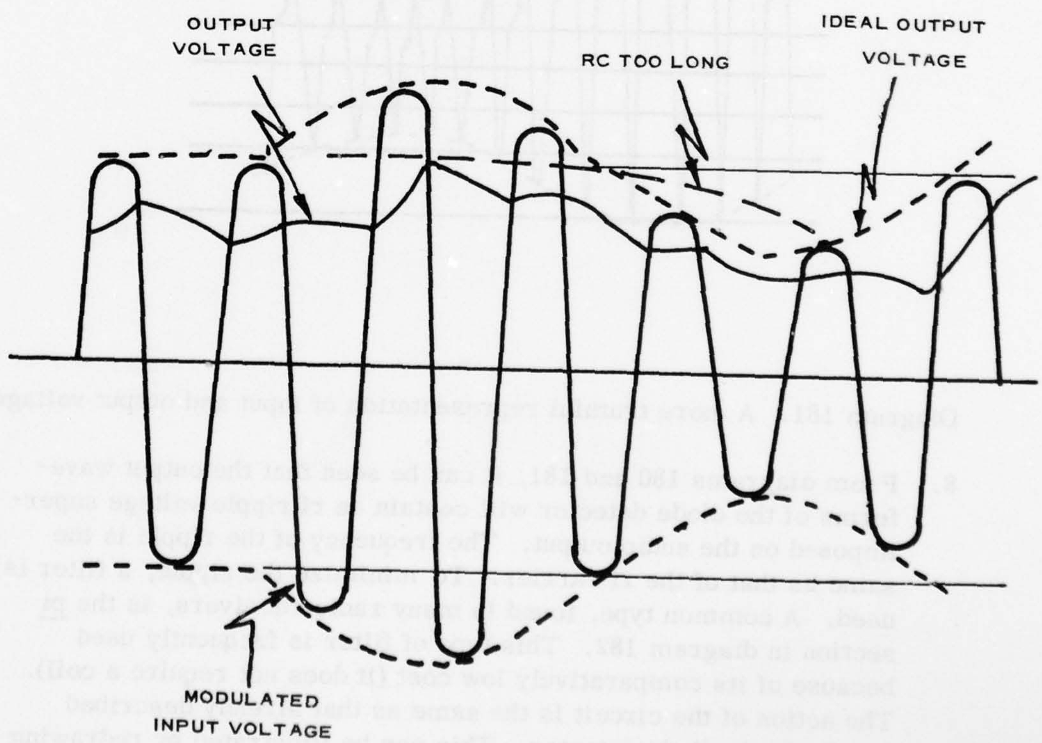

Diagram 180. How output voltage follows modulation of input rf wave.

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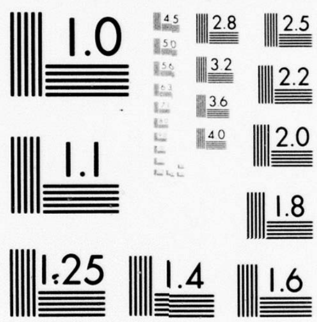

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e. A more accurate representation of the action is indicated in diagram 181. The value of the RC time constant to use for the detector is determined by the maximum rate of change of the amplitude. The capacitor discharge rate must be faster than the maximum rate of change of the amplitude or diagonal clipping will occur. On the other hand, the time constant should not be too small or an excessive amount of rf will appear in the output.

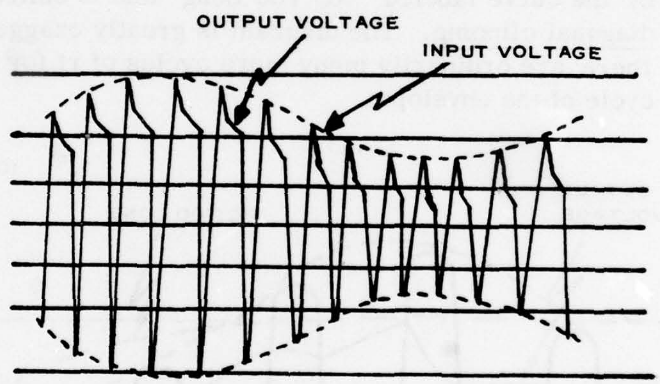

Diagram 181. A more truthful representation of input and output voltages.

8. From diagrams 180 and 181, it can be seen that the output waveforms of the diode detector will contain an rf ripple voltage superimposed on the audio output. The frequency of the ripple is the same as that of the rf carrier. To minimize the ripple, a filter is used. A common type, found in many radio receivers, is the pi section in diagram 182. This type of filter is frequently used because of its comparatively low cost (it does not require a coil). The action of the circuit is the same as that already described for the basic diode detector. This can be illustrated by redrawing the circuit as shown in diagram 183. It can be seen that the filter shunts the output load resistor. The diode rectifies the rf

signal, and the filter reduces the ripple on the audio output. Since the filter resistance is part of the load of the detector circuit, it will consume some of the audio power. However, the resistance is usually small compared with the load resistor and will not appreciably affect the sensitivity.

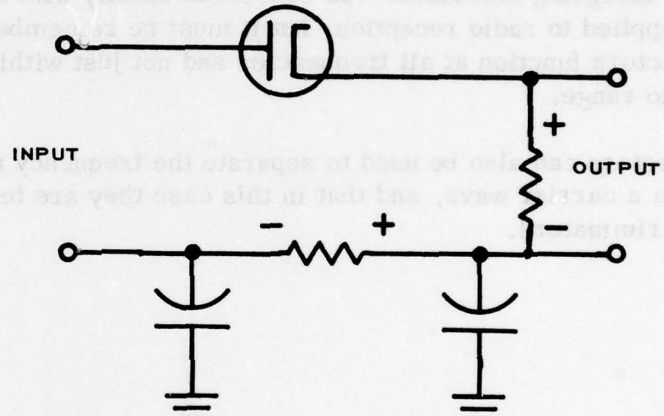

Diagram 182. Basic type of diode detector with a pi-filter to reduce output ripple.

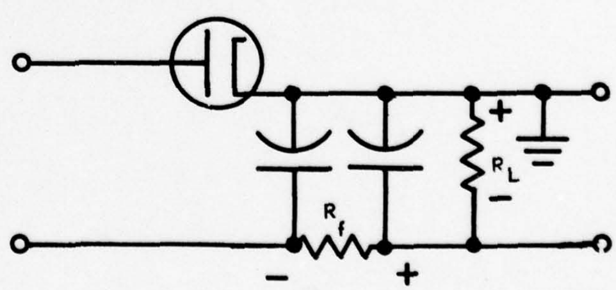

Diagram 183. Basic diode detector with pi-filter redrawn to indicate output.

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SUMMARY:

1. The detector is a device used to separate any information that modulates a carrier wave. It can be taken to be the exact opposite of a modulator.

2. The foregoing discussion was concerned chiefly with detectors as applied to radio reception, but it must be remembered that detectors function at all frequencies and not just within the audio range.

3. Detectors can also be used to separate the frequency modulation from a carrier wave, and that in this case they are termed discriminators.

LESSON PLAN

SUPERHETERODYNE RECEIVERS

OBJECTIVE:

To explain and demonstrate:

1. The deficiency of radio receivers before invention of the superheterodyne receiver,

2. The principle of heterodyning as utilized by the superheterodyne receiver, and

3. The block diagram of the superheterodyne receiver.

INTRODUCTION:

1. The operating principles of the superheterodyne receiver (hereafter called superhet) are used almost universally in present-day receiver design, and this lesson will explain principles involved in superhet operation.

2. Because of the superior performance of the superhet, as compared to any other type of radio receiver, it is used in radar, television, communications, and broadcast reception.

PRESENTATION:

1. The block diagram of a radio receiver is shown in diagram 184. Any radio receiver designed to reproduce speech or music will generally contain the elements shown.

   a. Voltages of many different frequencies are induced in the antenna by radio signals reaching it through space. The frequency of each induced voltage is the same as the frequency of the received radio wave.

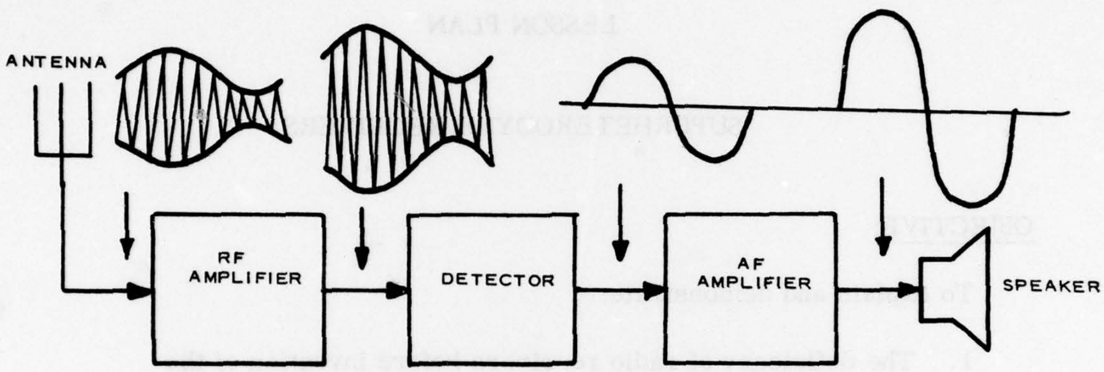


Diagram 184. Tuned rf receiver.

b. The radio-frequency amplifier contains resonant circuits and amplifier tubes arranged so as to pass and amplify signals of the desired frequency only. All other radio-frequency signals are blocked by the resonant circuits and do not appear in the rf amplifier output.

c. The signal passed by the rf amplifier is amplified to several hundred times its magnitude at the antenna. This signal is still amplitude-modulated and retains its original shape; only the magnitude of the signal has been changed.

d. The amplitude-modulated signal from the rf amplifier section passes to the detector which rectifies and filters the rf signal to produce an audio-frequency signal.

e. The audio-frequency output of the detector is amplified in one or more audio amplifier stages.

f. The output of the audio amplifier is applied to a speaker in order to reproduce the original sounds used to modulate the signal transmitted from the broadcast station.

2. Diagram 185 shows a block diagram of a superhet receiver.

   a. The block diagram of the superhet receiver contains the three blocks shown in diagram 184 since the functions of those blocks are essential to any radio receiver.

b. **The added blocks in the superhet receiver are the mixer (or converter), the local oscillator, and the intermediate-frequency (if) amplifier.**

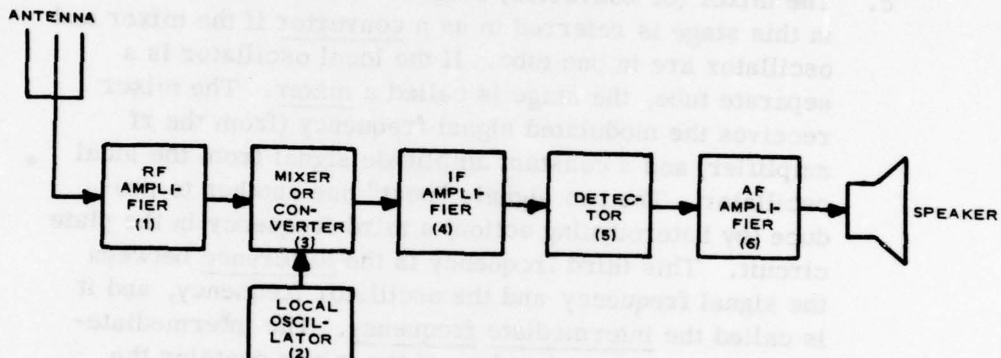


Diagram 185. Superheterodyne receiver.

3. **Operation of the superhet receiver (diag 185).**

   a. **Block 1 is the tunable radio-frequency amplifier which selects and amplifies an rf signal. Though this stage is often designed to amplify the rf signal, the primary purpose of the stage is that of providing selectivity. This is accomplished by means of tunable resonant circuits. Though the selectivity provided by the resonant circuits is not sufficient to reject frequencies that are near the desired frequency, it is sufficient to reject image frequencies which differ greatly from that of the desired frequency.**

   b. **Block 2 is the local oscillator. The local oscillator is tunable and is generally tuned by the same knob that tunes the rf amplifier. The frequency of the oscillator is normally higher than the frequency of the desired station. Regardless of the frequency of the station that is being received, the oscillator frequency is always higher (at broadcast station frequencies) than the station frequency**

by an amount equal to the intermediate frequency. This intermediate frequency remains the same regardless of the frequency of the rf signal.

c. The mixer (or converter) stage is block 3. The tube used in this stage is referred to as a converter if the mixer and oscillator are in one tube. If the local oscillator is a separate tube, the stage is called a mixer. The mixer receives the modulated signal frequency (from the rf amplifier) and a constant amplitude signal from the local oscillator. The two signals "beat" one another to produce (by heterodyning action) a third frequency in the plate circuit. This third frequency is the difference between the signal frequency and the oscillator frequency, and it is called the intermediate frequency. The intermediate-frequency signal at the plate of the mixer contains the same amplitude modulations that were present in the received signal.

d. The if amplifiers in block 4 are high-efficiency, high-gain, fixed-tuned amplifiers. They provide the required selectivity to reject signals from stations on adjacent broadcast channels. The if amplifiers always amplify the same frequency regardless of the frequency of the station to which the rf amplifiers are tuned.

e. Block 5 is the detector which rectifies the signal amplified by the if amplifiers. The rectified signal is filtered to remove the radio frequency and leave an audio-frequency signal which is passed to the audio-frequency amplifiers.

f. The audio-frequency amplifiers in block 5 usually consist of one voltage amplifier followed by a power amplifier to drive the speaker.

g. When the superhet receiver is designed for radar or television, block 6 contains video amplifiers, and the speaker is replaced by cathode-ray tubes.

SUMMARY:

1. The superheterodyne receiver has several important advantages over other types of receivers.

   a. In the superheterodyne circuit, the incoming signal is changed to a lower frequency, known as the intermediate frequency.

   b. The major part of the amplification takes place at this frequency before detection.

2. It is much easier to attain high levels of amplification of the received signal since it is necessary to design amplifiers that operate within a comparatively small band.

LESSON PLAN

OSCILLATORS

OBJECTIVE:

To explain and demonstrate:

1. The definition of an oscillator;
2. The conditions necessary for the occurrence of oscillations in a vacuum-tube circuit;
3. The functioning of the Hartley oscillator; tuned-plate, tuned-grid oscillator; and crystal oscillators; and
4. The uses of oscillators.

INTRODUCTION:

1. An oscillator is a vacuum-tube circuit which converts dc power into ac power.
2. A vacuum-tube oscillator is an amplifier which feeds back a small portion of the ac energy from the plate circuit to the grid of the same tube.
3. Vacuum-tube oscillators will develop ac voltage at frequencies far greater than is possible with mechanical ac generators.
4. The high-frequency limit of vacuum-tube oscillators depends on the transit time of electron flow from cathode to plate. The high-frequency limit occurs when the transit time occupies an appreciable portion of the time of one cycle.
5. The practical applications of vacuum-tube oscillators are almost unlimited. A few include:

   a. Controlling the output frequency of radio transmitters,

b. Synchronizing all circuit operations in a radar set,

c. Synchronizing oscillators in television receivers,

d. Remote controlling of switching operations in isolated power stations, or

e. Use as a local oscillator required in all superheterodyne receivers.

PRESENTATION:

1. For a vacuum tube to function as an oscillator, as shown in diagram 186, four basic requirements must be fulfilled.

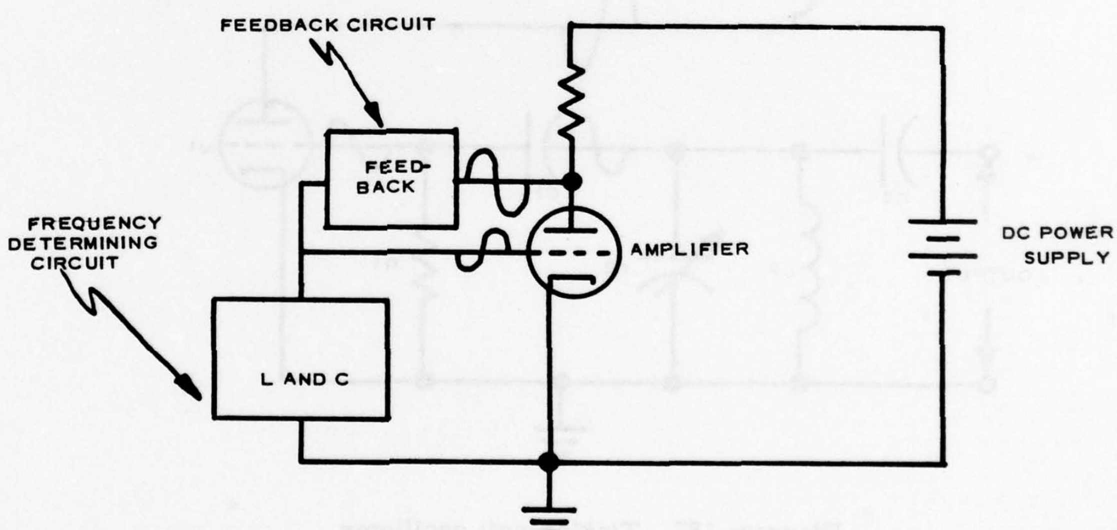


Diagram 186. Basic oscillator circuit.

a. There must be a dc power source.

b. There must be an amplifier tube.

c. The associated circuit must include frequency-determining components.

d. A feedback circuit must supply a signal to the grid in the proper phase. The ac voltage applied to the grid is 180° out of phase with the ac voltage on the plate.

2. A simple oscillator known as a tickler-coil oscillator is shown in diagram 187. The circuit operation is given below.

   a. The small signal shown on grid of V1 produces a sinusoidal current in the plate circuit.

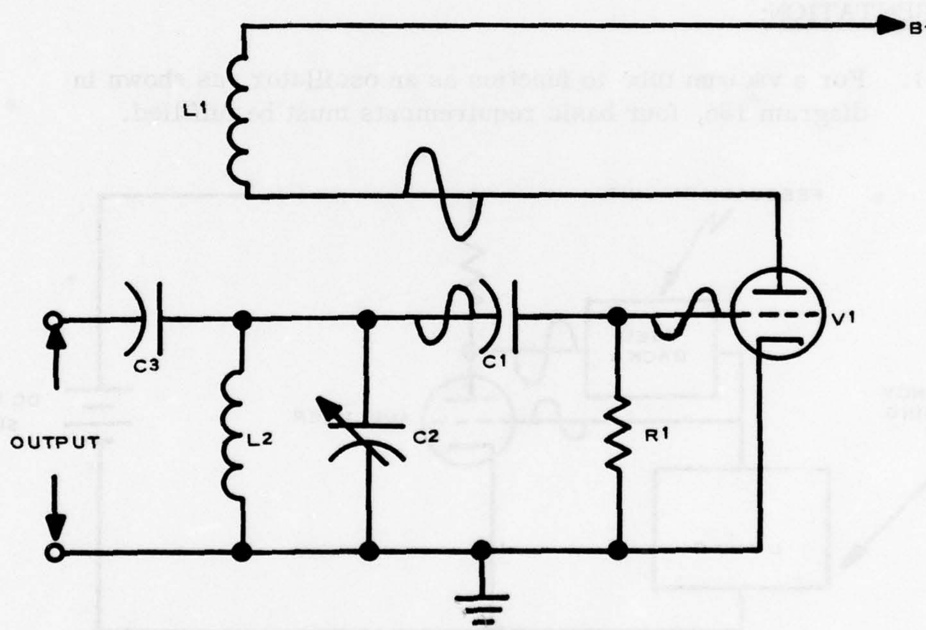


Diagram 187. Tickler-coil oscillator.

   b. This sinusoidal current flowing through L1 induces a voltage in L2 by transformer action. The voltage induced in L2 produces a sinusoidal voltage on the grid which is the sine wave mentioned above.

   c. Feedback is accomplished by inductive coupling between L1 and L2.

d. The frequency of the oscillator is determined by the resonant frequency of L2 and C2.

e. An output signal may be taken from across L2.

f. C1 and R1 produce bias for V1 by grid-leak action.

g. The plate and B+ connections to L1 should be such that the voltage induced in L2 is 180° out of phase with the voltage on the plate.

h. The tickler-coil oscillator is frequently used as the local oscillator in superheterodyne receivers.

3. A Hartley oscillator is shown in diagram 188.

a. The parallel circuit, consisting of C1 and L1, functions as both the feedback circuit and the frequency determining circuit. The arrow through C1 indicates that C1 is manually adjustable; and by varying C1, the resonant frequency of C1 and L1 is varied.

b. The coil L1 is centertapped, and the centertap is grounded. When an ac voltage is applied to one end of the coil, a voltage of opposite polarity (180° phase difference) appears at the other end.

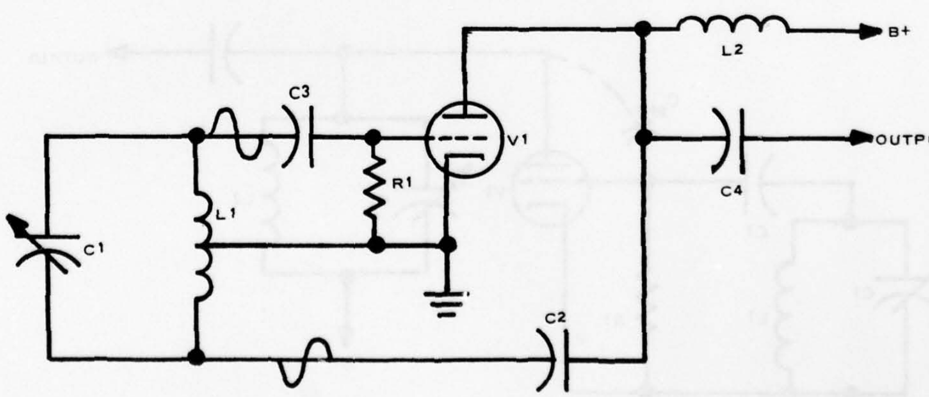


Diagram 188. Hartley oscillator.

c. The capacitor C2 blocks the dc plate voltage from reaching the resonant circuit, but the ac plate voltage passes freely.

d. The coil L2 is a radio-frequency choke which has high reactance at the frequency of operation. The ac voltage that appears on the plate of V1 is developed across L2.

e. Capacitor C3 and resistor R1 develop bias for V1 by grid-leak action.

f. The output may be taken from the plate through a capacitor, such as C4, or by capacitive coupling from the grid end of the resonant circuit.

4. A tuned-plate, tuned-grid oscillator is shown in diagram 189.

a. The oscillator requires two parallel resonant circuits (called tanks).

b. The frequency of oscillation is always slightly lower than the resonant frequency of either tank circuit. The lower oscillating frequency causes the tanks to be inductive, and the circuit will oscillate only at frequencies at which the tanks are inductive.

c. The feedback path from plate circuit to grid circuit is through the grid-to-plate capacitance within the tube as shown in diagram 189.

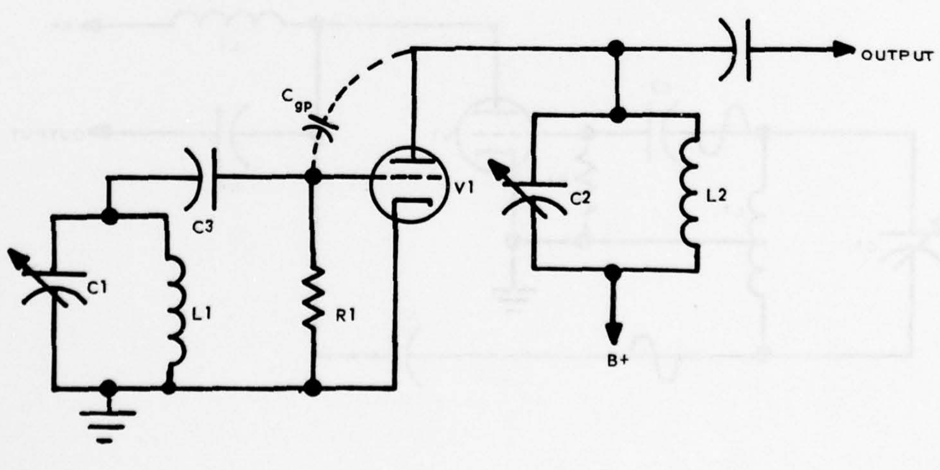


Diagram 189. Tuned-plate, tuned-grid oscillator.

d. The circuit has the disadvantage of having two tuning controls which must be varied simultaneously to change the frequency of operation.

e. Capacitor C3 and resistor R1 develop bias for V1 by grid-leak action.

f. The output may be capacitively coupled from the plate.

g. The tuned-plate, tuned-grid oscillator has no advantages when compared to other oscillators, but it is the basic circuit of the crystal oscillator shown in diagram 190.

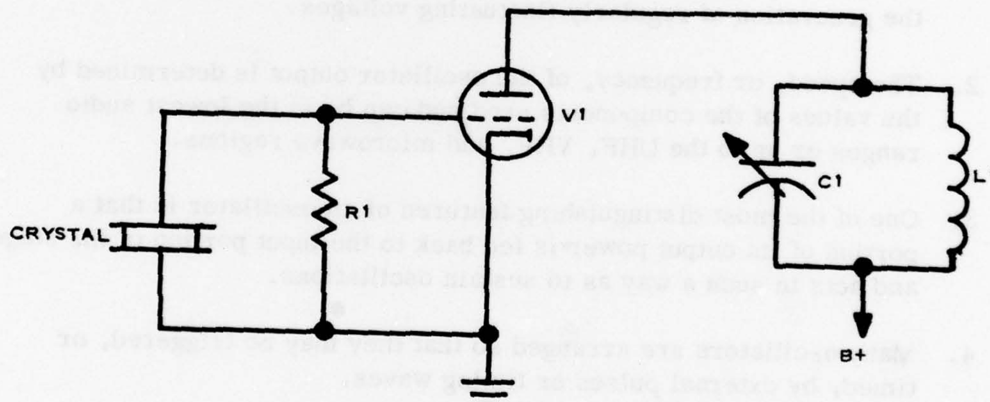


Diagram 190. Crystal oscillator.

5. The crystal oscillator shown in diagram 190 is described below.

a. The crystal shown in the grid circuit of the oscillator in diagram 190 is a thin slab of pure quartz having piezoelectric properties sandwiched between two brass electrodes. The quartz crystal will function as a parallel resonant circuit at only one frequency and will function in the circuit to produce oscillations of constant frequency.

b. Crystal oscillators have extremely good frequency stability and are usually used where the frequency must remain constant.

c. The plate tank in the crystal oscillator is adjusted for maximum voltage output, but it has practically no effect on the frequency of the output.

6. There are many more types of oscillators than have been illustrated in this lesson, but most other types are derived from the basic circuits presented here.

SUMMARY:

1. Many types of oscillators are used in all phases of electronics for the generation of regularly fluctuating voltages.

2. The speed, or frequency, of the oscillator output is determined by the values of the components used and can be in the lowest audio ranges or up to the UHF, VHF, and microwave regions.

3. One of the most distinguishing features of an oscillator is that a portion of its output power is fed back to the input portion of the stage and acts in such a way as to sustain oscillations.

4. Many oscillators are arranged so that they may be triggered, or timed, by external pulses or timing waves.

LESSON PLAN

TRANSMITTER AND RECEIVER

OBJECTIVE:

To explain the operation of, and the problems encountered in, radio transmitters and receivers.

PRESENTATION:

INSTRUCTOR'S NOTE: For simplicity, use blocks to denote the various stages which comprise the transmitters to be discussed.

1. Simple Transmitter.

   a. The simplest type of transmitter consists only of an oscillator directly connected to the antenna (diag 191).

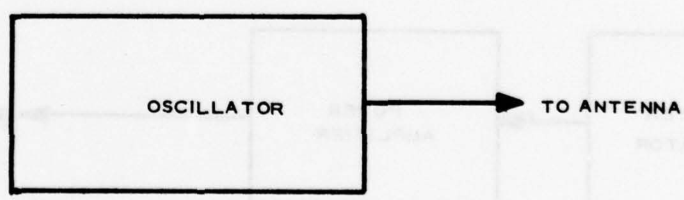


Diagram 191. Simple transmitter.

   b. The oscillator can consist of a single tube; and if it is desired to increase the output, it is only necessary to increase the working voltages and use a larger tube.

   c. The frequency stability of this oscillator cannot be maintained to any degree now considered satisfactory.

INSTRUCTOR'S NOTE: Explain that the frequency of oscillation is a function of the reactances of the oscillatory circuit, and that a slight change in capacity between antenna and ground will reflect back to the oscillatory circuit and cause a corresponding frequency drift.

d. This frequency drift appears especially when the wind is blowing, on board ship, or in aircraft. In any case, the antenna changes its position with respect to ground, and the frequency drifts accordingly.

2. Improved Transmitter.

a. To overcome this deficiency of the simple transmitter, the master oscillator-power amplifier transmitter was developed.

b. This system has a decided advantage over the simple transmitter in that the frequency stability is greatly improved. This is due, primarily, to the fact that the antenna is not coupled directly to the oscillator and also because the oscillator is not loaded so much.

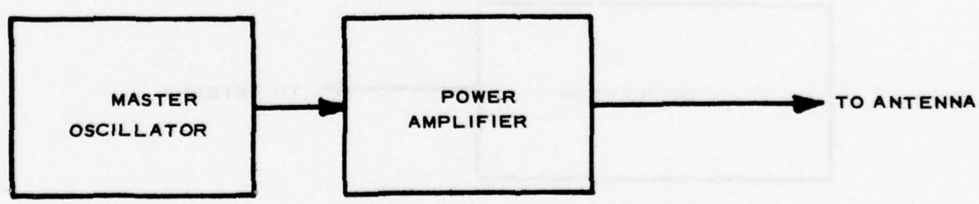


Diagram 192. Improved transmitter.

c. The master oscillator is coupled to a load of constant reactance; therefore, its frequency is constant.

d. If the capacitance between antenna and ground changes, the only effect will be a change in the power transfer between the power amplifier and the antenna. This effect is usually unnoticeable.

e. The master oscillator, power amplifier system is referred to as the MOPA transmitter.

INSTRUCTOR'S NOTE: Discuss the unmodulated carrier. Explain that, since it is unmodulated, it can carry no intelligence; although, in wireless telegraphy, intelligence can be conveyed from one place to another by interrupting the carrier periodically and thereby forming the familiar dots and dashes of Morse code.

3. Modulation.

a. The process wherein some characteristic of the carrier wave is varied in accordance with a sound wave is known as modulation.

b. The carrier can be modulated by several methods:

1) Amplitude modulation,

2) Phase modulation, and

3) Frequency modulation.

INSTRUCTOR'S NOTE: Discuss the different types of modulation and their effect on the carrier.

c. Amplitude-modulated transmitter.

1) In this type of transmitter, the oscillator develops a constant amplitude carrier.

2) The modulator varies the amplitude of the carrier in accordance with a sound wave.

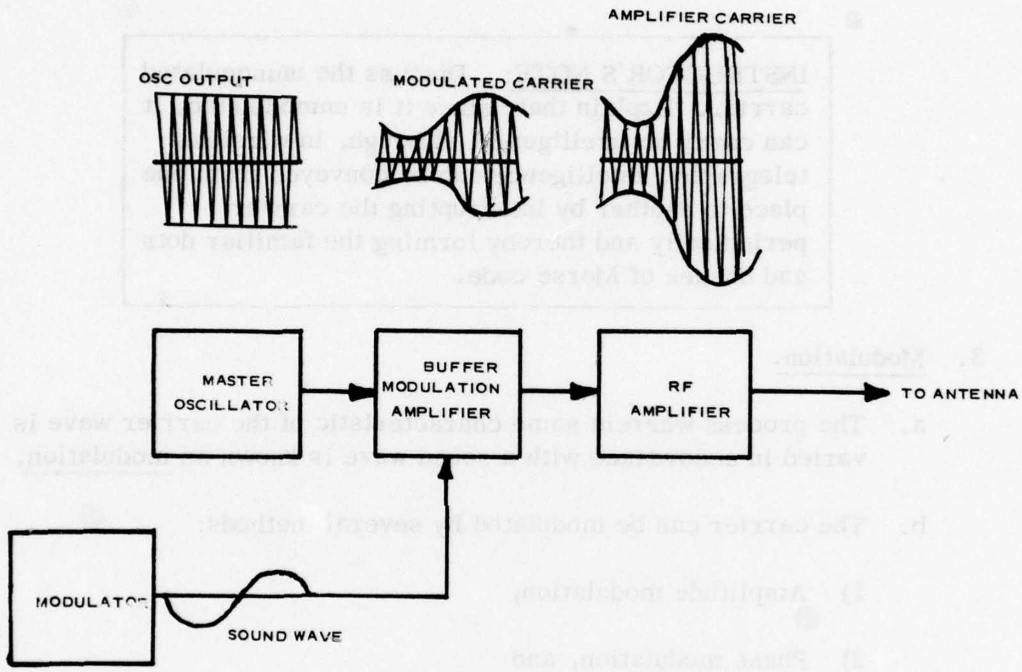


Diagram 193. Block diagram of a simple carrier-wave transmitter.

3) **The modulated carrier is then sent to the rf amplifier for amplification before it is sent to the antenna and radiated into space.**

4) **The transmitter in diagram 193 is necessarily a basic one. However, the principles involved are universal in amplitude-modulated transmitters. The choice and type of components are determined by the power and frequency stability required.**

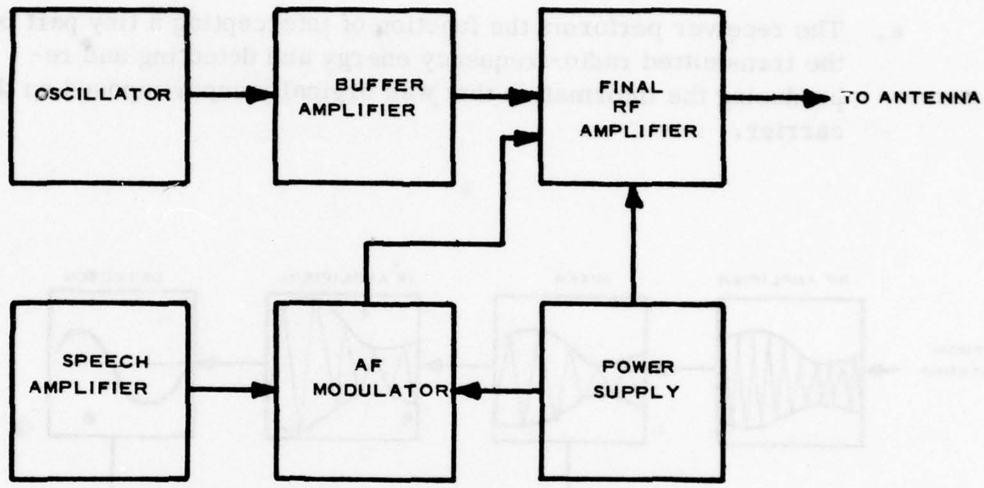


Diagram 194. Block diagram of amplitude-modulated transmitter.

d. AM transmitter of diagram 194.

1) The sound energy of the voice is transformed to a feeble voltage variation in the microphone and sent to the speech amplifier.

2) The output of the speech amplifier is further amplified in the af modulators and sent to the final rf amplifier.

3) The outputs of the modulator and the buffer amplifier are mixed in the final rf amplifier to produce the modulated carrier.

4) Smaller transmitters have a power supply which is capable of supplying power to both the af and rf sections. Larger transmitters use a separate supply for each section.

4. Receiver.

a. The receiver performs the function of intercepting a tiny part of the transmitted radio-frequency energy and detecting and reproducing the information that was orginally superimposed on the carrier.

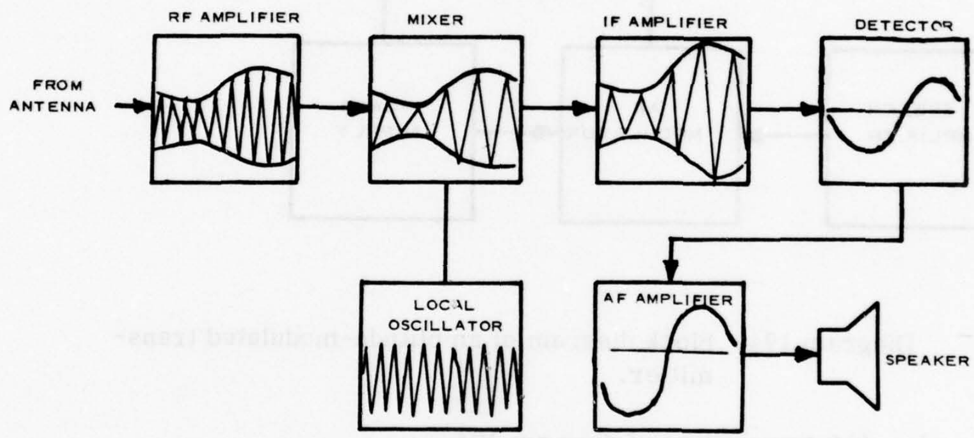


Diagram 195. Simplifier superheterodyne receiver.

b. The rf amplifier accepts the tiny rf voltage variations picked up by the antenna and amplifies them.

c. The local oscillator generates a signal that is at a fixed frequency difference with respect to the incoming rf signal.

d. The mixer or converter receives both the rf signal and the local oscillator output and mixes the two. The resulting output frequency will be the difference of the two input signals.

INSTRUCTOR'S NOTE: Briefly explain the mixing action of the converter and how the if signal is formed.

e. The if signal from the mixer section is amplified in the following stage, the if amplifier, and sent to the detector. The frequency of the if signal is the frequency difference between the incoming rf signal and the local-oscillator frequency.

<u>Example:</u> Incoming rf is = 900 kc.

Local oscillator frequency = 1,355 kc.

IF signal = 455 kc.

The envelope of the if signal, however, will remain identical to the envelope of the incoming rf signal.

f. The process of mixing the rf signal with the output from the local oscillator is known as heterodyning, and a receiver that employs the heterodyne principle is known as a superheterodyne.

g. The output of the if amplifier is sent to the detector stage which rectifies the input signal so that one half (either positive or negative) of the envelope is removed. The if component of the remaining half of the envelope is removed, and the remaining audio signal is fed to the af amplifier.

h. The audio output of the detector is sent to the audio-frequency amplifier for additional amplification before application to the voice coil of the loudspeaker.

i. The loudspeaker will then change the audio-frequency voltage variations into sound variations that closely approximate the original sound that was picked up by the microphone of the transmitter.

<u>SUMMARY:</u>

1. The function of any transmitter is to generate rf energy at various levels of power with a frequency stability within prescribed limits.
2. A further function of the transmitter is to modulate the generated rf energy by some means which causes the rf or carrier wave to fluctuate in accordance with the information it is desired to transmit.

SUMMARY (continued)

3. **The function of any receiver is the exact reverse; that is, to separate the carrier from the modulating information and to present this information in some form to the using party.**

LESSON PLAN

VOLTAGE-REGULATOR TUBES

OBJECTIVE:

To explain and demonstrate:

1. The uses of voltage-regulator (VR) tubes,
2. The basic voltage-regulator circuit using VR tubes,
3. How VR tubes may be used in series, and
4. The limitations of VR tubes.

INTRODUCTION:

1. A voltage regulator is an electronic device placed in the output of a power supply to maintain the output voltage at its rated value. It reacts automatically, within its rated limits, to any variation of the output voltage.
2. VR tubes are used to provide a constant voltage to circuits whose supply voltage must remain constant regardless of variations in load current. The use of VR tubes, however, is limited to load currents that vary between zero and 35 milliamperes (25 ma for some miniature VR tubes).
3. For proper operation, the current that may pass through a VR tube must not be less than 5 milliamperes or more than 40 milliamperes (30 ma for some miniature VR tubes).

PRESENTATION:

1. Voltage-Regulator Tubes.

   a. Voltage-regulator tubes are gas-filled diodes with no heated filament.

b. Diagram 196(1) shows the schematic symbol for a VR tube, and diagram 196(2) shows the actual construction. The cathode is a metal cylinder with a wire anode extending through the axis of the cylinder.

INSTRUCTOR'S NOTE: Pass a VR tube around for the class to examine.

c. The two elements are inclosed in a glass envelope which is filled with an inert gas (neon, argon, or krypton) at a very low pressure. The dot within the circle of the tube symbol indicates a gas-filled tube (diag 196).

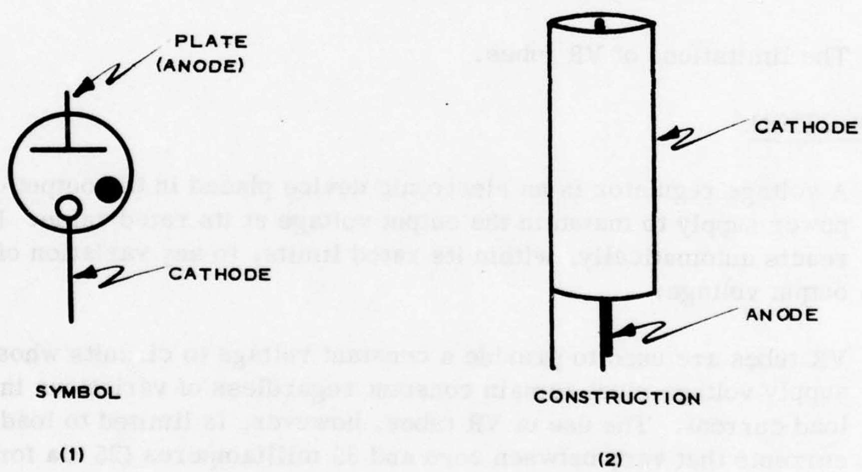


Diagram 196. Voltage-regulator tube.

d. Though a relatively high voltage (anode positive with respect to cathode) is necessary to ionize gas, once the gas is ionized the voltage drop falls to a constant value and will remain constant over a wide range of currents. In general, the ionizing potential is about 20 percent greater than the normal drop during conduction.

e. VR tubes are manufactured for four operating voltage drops: 75, 90, 105, and 150 volts.

2. Circuitry.

a. The circuit associated with a VR tube must be arranged to limit the maximum current through the tube to 40 milliamperes and the minimum current to 5 milliamperes.

b. A VR tube is shown in diagram 197, and the following statements apply to that circuit.

> INSTRUCTOR'S NOTE: Use the classroom demonstrator to show the circuit and operation of the circuit.

1) The resistor R is always necessary in order to develop a voltage drop equal to the difference between the power-supply voltage and the drop across the VR tube. Resistor R is the current-limiting resistor.

2) In diagram 197, a VR150 is used. The output voltage is 150 volts. Since the power supply voltage is 400 volts, the drop across R will be 250 volts. When no load is connected to output terminals X and Y, the maximum current flows through the VR tube. The maximum allowable current is 40 milliamperes, and this same current flows through R.

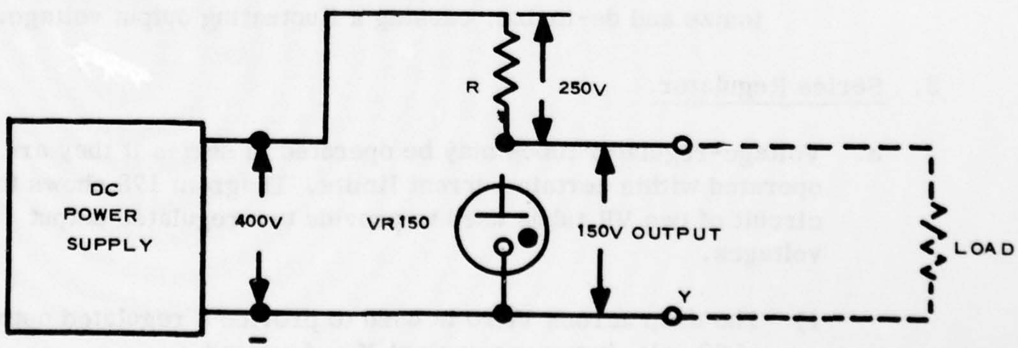


Diagram 197. Voltage regulator circuit.

3) The value of R can be calculated by Ohm's law since the voltage drop (250 volts) and the current (40 ma) are known.

$$R = \frac{E}{I} \text{ (equation (2))}$$

$$= \frac{250}{0.04} = 6,250 \text{ ohms.}$$

4) If a 150,000-ohm load is connected to the terminals, the current through the load is 1 milliampere, and the current through the VR tube drops to 39 milliamperes. The current through R remains 40 milliamperes.

5) When a 10,000-ohm load is connected to the output, the current through the load is 15 milliamperes, and the current through the VR tube drops to 25 milliamperes.

6) The minimum value of load resistance that may be connected to the output is 4,285 ohms. This value of load resistance will pass 35 milliamperes and leave 5 milliamperes through the VR tube.

7) The voltage drop across the VR150 will remain at 150 volts for all values of load resistance mentioned above. If, however, a load that passes more than 35 milliamperes is connected to the output, the current through the VR tube falls below 5 milliamperes, and the tube tends to rapidly ionize and de-ionize, causing a fluctuating output voltage.

3. Series Regulator.

a. Voltage-regulator tubes may be operated in series if they are operated within certain current limits. Diagram 198 shows the circuit of two VR tubes used to provide two regulated output voltages.

1) The drop across VR90 is used to provide a regulated output of 90 volts between terminal X and ground.

2) The drop across both tubes, 195 volts, is used as a second output between terminal Y and ground.

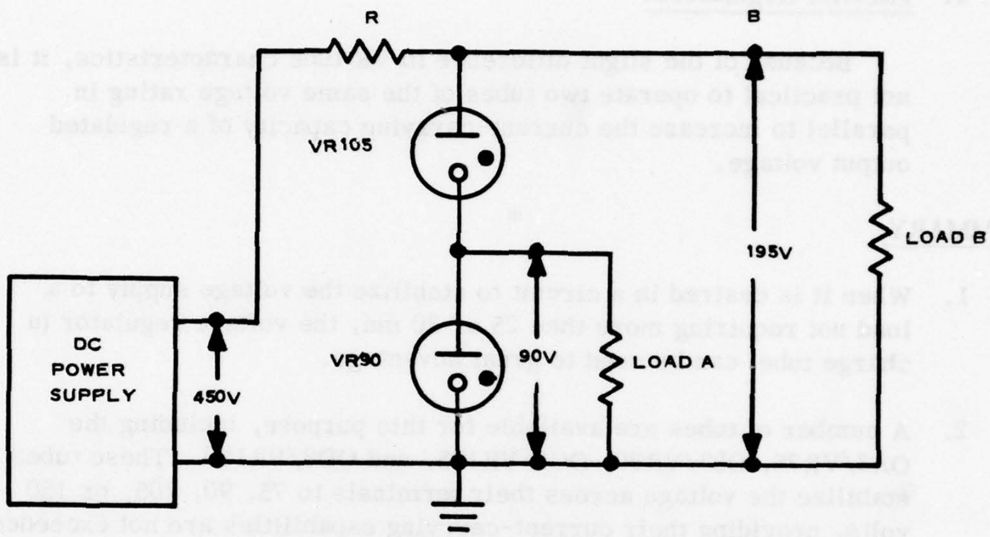


Diagram 198. Voltage regulator tubes in series.

3) The total current passed by both loads, X and Y, must not exceed 35 milliamperes.

4) The current through the series resistor R is a constant 40 milliamperes.

5) The voltage drop across R is the power supply voltage minus the sum of the tube drops:

$$E_R = E_b - (E1 + E2 + E3 \ldots E_n) \qquad (59)$$

$$E_R = 450 - 195 = 255 \text{ volts.}$$

6) The value of R is determined by Ohm's law, equation (2):

$$R = \frac{255}{0.04} = 6,375 \text{ ohms.}$$

4. Parallel Regulators.

Because of the slight difference in VR tube characteristics, it is not practical to operate two tubes of the same voltage rating in parallel to increase the current-carrying capacity of a regulated output voltage.

SUMMARY:

1. When it is desired in a circuit to stabilize the voltage supply to a load not requiring more than 25 or 30 ma, the voltage regulator (a charge tube) can be used to great advantage.

2. A number of tubes are available for this purpose, including the OA3/VR75, OB3/VR90, OC3/VR105, and OD3/VR150. These tubes stabilize the voltage across their terminals to 75, 90, 105, or 150 volts, providing their current-carrying capabilities are not exceeded.

LESSON PLAN

DIODE LIMITERS

OBJECTIVE:

To explain and demonstrate:

1. The purpose of diode limiters,
2. The four basic diode limiter circuits, and
3. The way in which the limiting voltage is affected by bias voltages.

INTRODUCTION:

1. Diode limiters are essentially waveshapers.
2. A diode limiter removes (or clips off) a part of a waveform without affecting the rest of the waveform.
3. Limiters which remove (or clip off) all parts of a waveform that are positive with respect to a reference voltage are referred to as positive limiters. If the limiter removes all parts of a waveform that are negative with respect to a reference voltage, it is called a negative limiter.

PRESENTATION:

> INSTRUCTOR'S NOTE: Use the classroom demonstration board to show the operation of diode limiters.

1. Diagram 199(1) shows a series-diode, negative limiter. The following statements describe its operation.

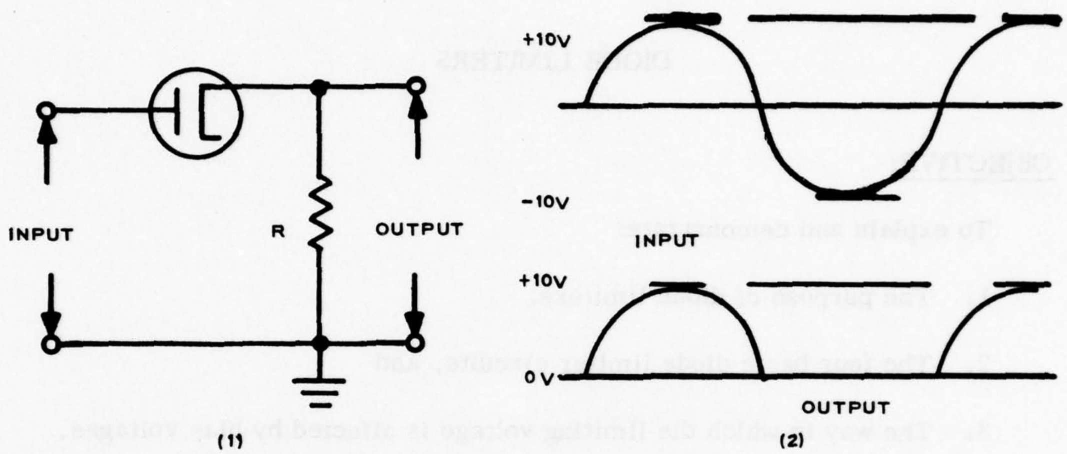


Diagram 199. Series-diode, negative limiter.

a. The circuit of diagram 199(1) is called a series-diode limiter because the diode is in series with the input and output terminals, and the signal must pass through the diode to reach the output terminal.

b. The circuit is a negative limiter because an input signal, such as the upper waveform shown in diagram 199(2), will be changed by the circuit to the lower waveform shown in diagram 199(2). The output waveform will consist of the positive half-cycles of the input, but the negative half-cycles will be absent.

c. Any part of the input signal which causes the diode to conduct will be passed on to the output terminal. Since the positive half-cycles of the input signal drive the plate of the diode positive with respect to the cathode, only the positive half-cycles reach the output terminal. The negative half-cycles of the input signal drive the plate negative with respect to the cathode, which prevents conduction in the diode, so the negative half-cycles are blocked.

d. In the series-diode, negative limiter of diagram 199 (1), the reference voltage (the voltage at which limiting occurs) is zero (or ground).

2. If the diode in diagram 199 (1) is reversed, so that the input terminal is connected to the cathode and the output terminal is connected to the plate, the circuit becomes a series-diode, positive limiter (diag 200).

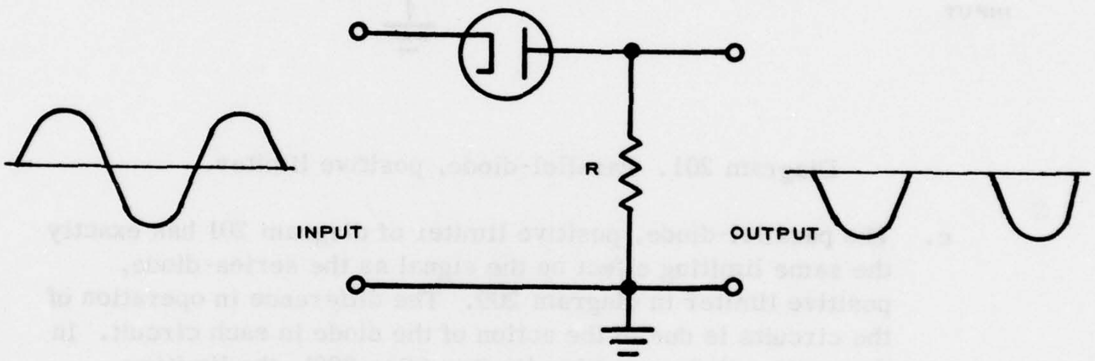


Diagram 200. Series-diode, positive limiter.

3. A parallel-diode, positive limiter is shown in diagram 201.

a. The positive half-wave of the input signal drives the plate of the diode positive with respect to the cathode which is grounded. When the plate rises slightly, a current flows through the diode and R. The resistance of R is much greater than the resistance of the diode during the time that the diode is conducting. Therefore, most of the voltage drop will appear across R; very little drop will appear across the diode, and thus, the output voltage will be very small.

b. The negative half-cycle of the input signal drives the plate of the diode negative with respect to the cathode, and the diode cannot conduct. Since no current can flow through R, there is no voltage drop across R, and the entire negative half-cycle of voltage appears at the output terminal.

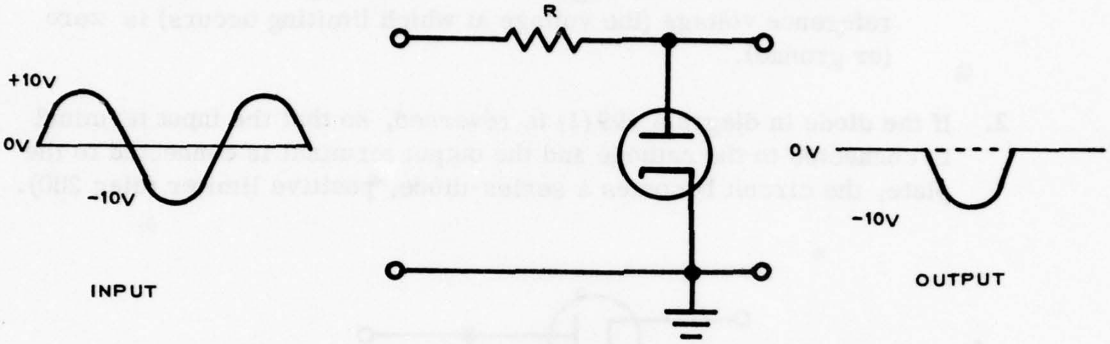


Diagram 201. Parallel-diode, positive limiter.

c. The parallel-diode, positive limiter of diagram 201 has exactly the same limiting effect on the signal as the series-diode, positive limiter in diagram 200. The difference in operation of the circuits is due to the action of the diode in each circuit. In the series-diode, positive limiter (diag 200), the limiting action occurs when the diode is not conducting; while in the parallel-diode, positive limiter, the limiting action occurs when the diode is conducting.

4. If the diode in the circuit of diagram 201 is inverted, the limiting effect is reversed; and the circuit becomes a parallel-diode, negative limiter as shown in diagram 202. The parallel-diode, negative limiter of diagram 202 will have exactly the same limiting effect on the signal as the series-diode, negative limiter of diagram 199.

5. Each of the four basic diode limiters that have been explained so far has only two elements in the circuit; a resistor and a diode. In the series-diode limiter (diags 199 and 200), the diode is the series element between the input and output terminals: The parallel element is the resistor connected between ground and the output terminal. In the parallel-diode limiters (diags 201 and 202), the resistor is the series element connected between the input and output terminals: The diode is the parallel element connected in parallel with the two output terminals.

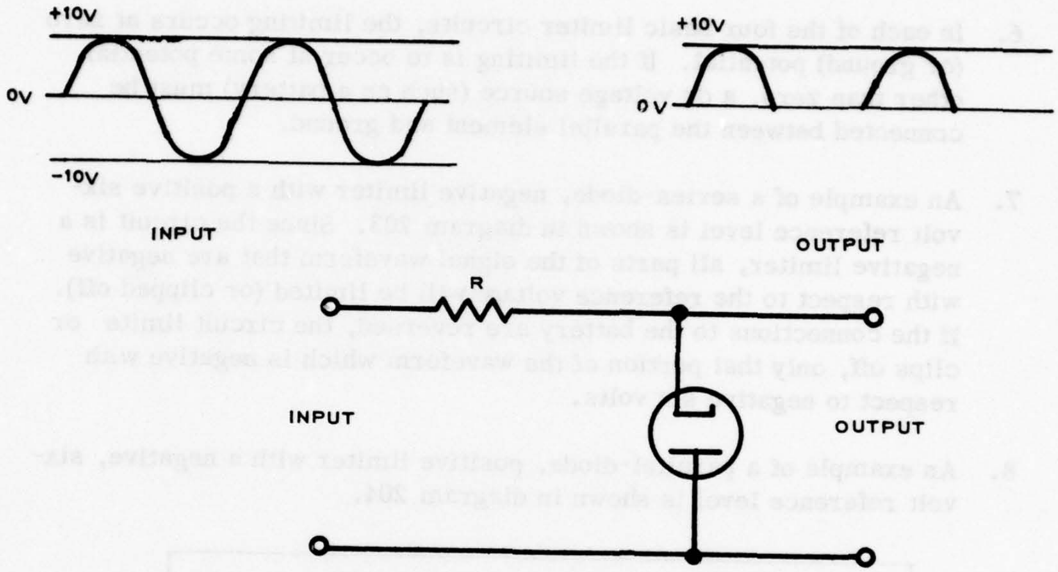


Diagram 202. Parallel-diode, negative limiter.

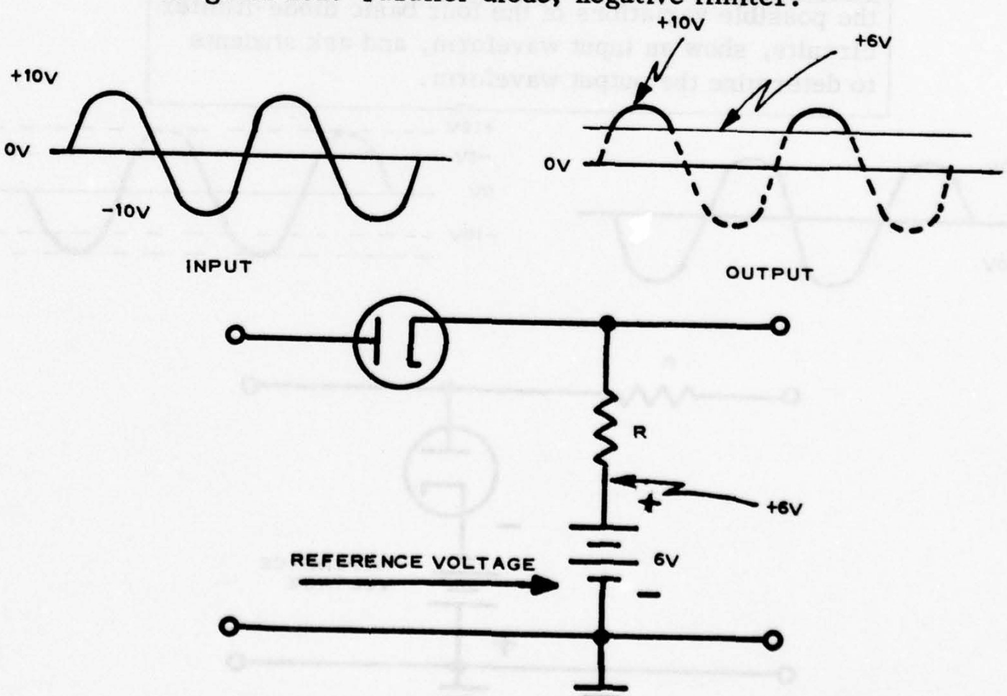


Diagram 203. Series-diode, negative limiter with positive reference voltage.

6. In each of the four basic limiter circuits, the limiting occurs at zero (or ground) potential. If the limiting is to occur at some potential other than zero, a dc voltage source (such as a battery) must be connected between the parallel element and ground.

7. An example of a series-diode, negative limiter with a positive six-volt reference level is shown in diagram 203. Since the circuit is a negative limiter, all parts of the signal waveform that are negative with respect to the reference voltage will be limited (or clipped off). If the connections to the battery are reversed, the circuit limits or clips off, only that portion of the waveform which is negative with respect to negative six volts.

8. An example of a parallel-diode, positive limiter with a negative, six-volt reference level is shown in diagram 204.

> INSTRUCTOR'S NOTE: Draw on the blackboard all the possible variations of the four basic diode-limiter circuits, show an input waveform, and ask students to determine the output waveform.

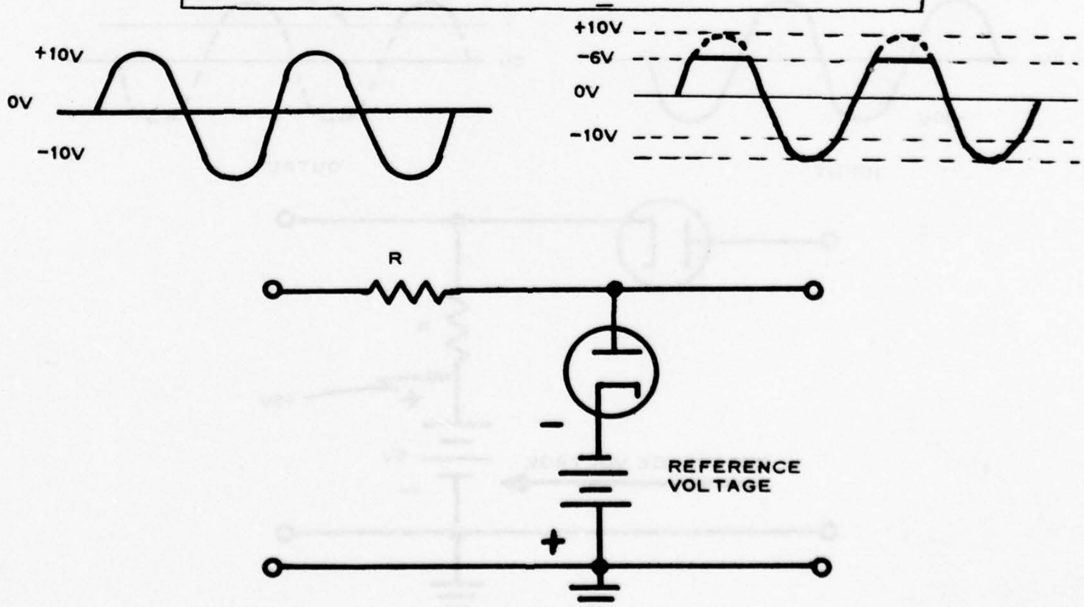


Diagram 204. Parallel-diode, positive limiter with negative reference voltage.

SUMMARY:

1. The characteristics of a diode are such that the tube conducts only when the plate is at a positive potential with respect to the cathode.

   a. A positive potential may be placed on the cathode in which case the tube will not conduct till the plate surpasses an equally positive value.

   b. As the plate becomes more positive with respect to the cathode, the diode conducts and passes the portion of the waveform that is more positive than the cathode.

2. Diodes may be used as series or parallel limiters and may also be biased so that only a certain portion of a waveform is passed.

LESSON PLAN

DIODE CLAMPERS

OBJECTIVE:

To explain and demonstrate:

1. The purpose of diode clamping,
2. The diode clamping circuit, and
3. The circuit arrangements of diode clampers which must clamp waveforms to voltage levels that are not zero (ground).

INTRODUCTION:

1. A clamping circuit, also called a direct-current restorer, shifts a waveform so that it is all above, or all below, a certain voltage (often zero voltage).

2. The clamping circuit is so named because it clamps the positive or negative peaks of a waveform at a certain voltage which may be zero, any positive voltage, or any negative voltage, depending on the arrangement of the circuit.

PRESENTATION:

1. Diagram 205 is an amplifier whose output is a series of negative pulses. The RC-coupling circuit consisting of C2 and R2 will produce a waveform on the output terminal X which is alternating in character because the positive extreme is at a positive 10 volts, and the negative extreme is at a negative 50 volts.

   a. The RC-coupling circuit consisting of C2 and R2 can produce only an output which is alternating, and the average voltage at terminal P will be zero.

b. The output waveform will always go both positive and negative with respect to ground (zero) by amounts which will make the area X equal to the area Y.

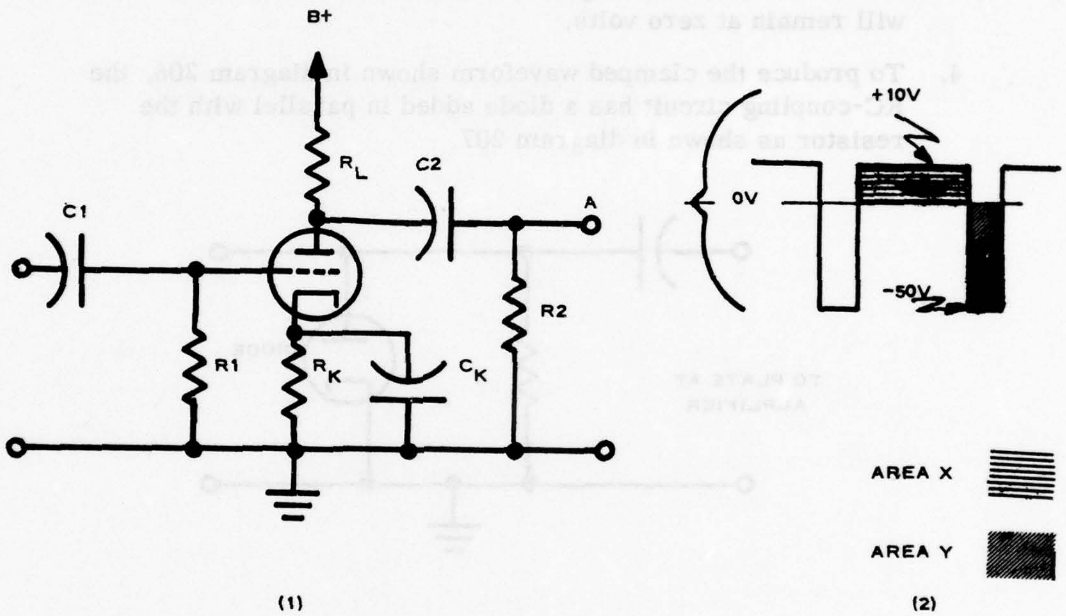


Diagram 205. Effect of RC-coupling circuit.

2. In many radar circuits, the negative output pulse of an amplifier must be coupled out by means of a coupling circuit that produces only negative pulses with no part of the waveform going positive with respect to ground (diag 206).

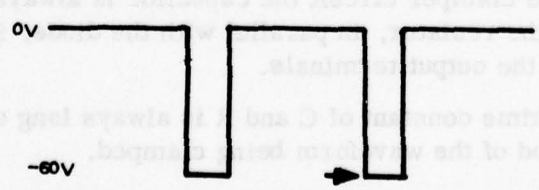


Diagram 206. Clamped waveform.

3. The waveform in diagram 206 is referred to as a clamped waveform. If the amplitude of the negative pulses produced by the amplifier increases, the negative peaks in diagram 206 will extend further in the negative direction, but the positive extreme will remain at zero volts.

4. To produce the clamped waveform shown in diagram 206, the RC-coupling circuit has a diode added in parallel with the resistor as shown in diagram 207.

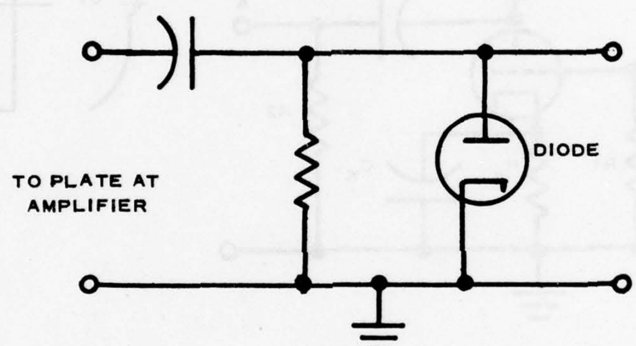


Diagram 207. Negative clamper.

a. The negative clamper shown in diagram 207 will clamp any waveform (sine wave, square wave, negative pulses, etc.) negative with respect to ground.

b. In comparison with the limiters which have only one resistor and one diode, the clamping circuit has a capacitor, a resistor, and a diode.

c. In the clamper circuit the capacitor is always a series element, and the resistor, in parallel with the diode, is always in parallel with the output terminals.

d. The time constant of C and R is always long compared to the period of the waveform being clamped.

e. The resistance of R is always very high compared to the resistance between cathode and plate of the diode when it is conducting.

f. The detailed explanation of how clamping is accomplished in the circuit of diagram 207 is unimportant. The important facts about the clamping circuit are the circuit arrangement and what it does.

5. A positive clamping circuit is similar to the circuit of diagram 207, but the connections to the diode are reversed as shown in diagram 208.

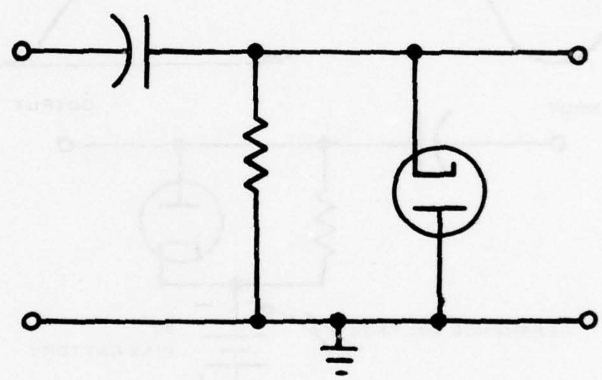


Diagram 208. Positive clamper.

a. The positive clamper will clamp any waveform (sine wave, square wave, pulse, etc.) positive with respect to zero.

b. The relationship between components in the negative clamper applies also to the positive clamper.

6. The two basic circuits for clamping circuits are shown in diagrams 207 and 208.

7. An easy way to distinguish a positive or negative clamper is to observe the diode symbol. If the cathode in the diode appears to be a hook which pulls downward (diag 207), the circuit is a negative clamper. If the cathode appears to be a hook which pulls upward (diag 208), the circuit is a positive clamper.

8. If a waveform must be clamped positive or negative from a voltage other than zero (ground), a dc voltage source must be connected between ground and both parallel components. As an example, diagram 209 shows a negative clamper which clamps any waveform negative with respect to negative five volts.

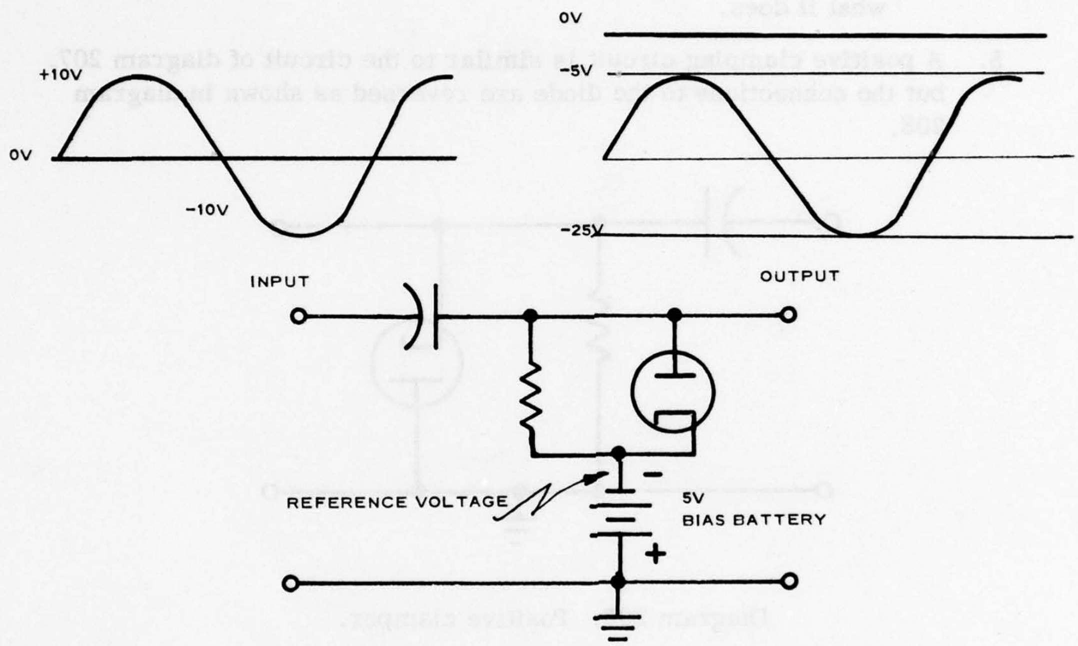


Diagram 209. Negative clamper with negative reference voltage.

9. If the diode in diagram 207 were reversed, the circuit would clamp any waveform positive with respect to a negative five volts.

> **INSTRUCTOR'S NOTE: Draw on the blackboard and explain all combinations of clamping circuits not given in this lesson plan.**

SUMMARY:

1. A circuit which holds either amplitude extreme of a waveform to a given reference level of potential is called a clamping circuit, or a dc restorer.

2. Clamping circuits can be used after RC-coupling circuits where the waveform swing is required to be either above or below the reference voltage instead of alternating on both sides of it.

3. Clampers are usually encountered in oscilloscopes where it is desired that the sweep trace begin at the same point each time. The start of the sweep can be positioned by adjusting the dc voltage applied to the clamping tube.

LESSON PLAN

DC AMPLIFIERS

OBJECTIVE:

1. To present dc amplifiers and their associated components, and

2. To discuss the operation of dc amplifiers.

INTRODUCTION:

The direct-current amplifier, or direct-coupled amplifier, is used for the amplification of very slowly varying voltage. It is also used when dc output voltage is desired. DC amplifiers are used frequently in radar applications. A basic understanding of the make-up and operation of the dc amplifier is a necessity since computers generally employ many dc amplifiers.

PRESENTATION:

1. A simple dc amplifier consists of a single tube with a grid resistor across the input terminals and with the load in the plate circuit (diag 210). E_c supplies grid bias, and E_b furnishes plate voltage.

2. The load of the dc amplifier may be a mechanical device such as a relay, a meter, or a counter. The output voltage may be used to control the gain of an amplifier.

Note: The last-mentioned usage of dc amplifiers is most common for computers. Another common use of dc amplifiers is in vacuum-tube voltmeters. The other uses are employed occasionally in radar.

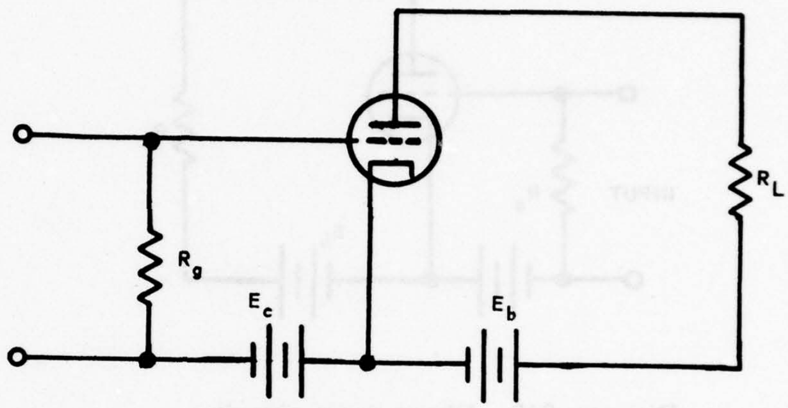


Diagram 210. DC amplifier.

3. The voltage to be amplified must be applied directly to the grid of the amplifier tube.

   a. Direct coupling is required in the input circuit.

   b. Two types of input circuit are shown below.

      1) Diagram 211 is a capacitor-input circuit.

      2) Diagram 212 is a direct-input circuit.

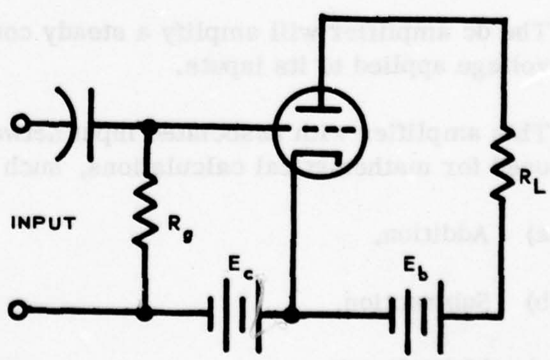


Diagram 211. Capacitor-input circuit.

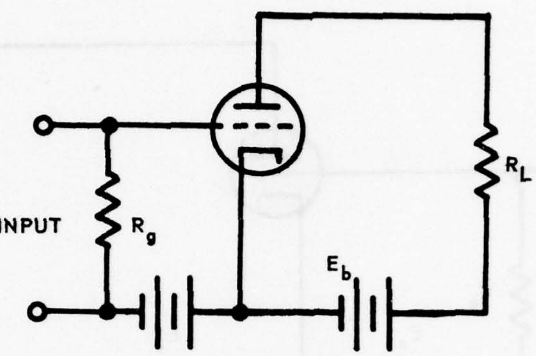


Diagram 212. Direct-input circuit.

INSTRUCTOR'S NOTE: Develop the output from each of these two types of dc amplifiers.

4. The capacitor input amplifier has a poor frequency response at low frequencies.

5. The direct-input amplifier has a similar response to all frequencies.

6. The advantages and disadvantages of dc amplifiers are listed below.

   a. Advantages.

      1) The dc amplifier will amplify a steady component of voltage applied to its inputs.

      2) This amplifier with associated input networks can be used for mathematical calculations, such as:

         a) Addition,

         b) Subtraction,

         c) Multiplication,

d) Division,

e) Differentiating, and

f) Integrating.

Note: These mathematical calculations are used in the dc amplifier circuits of the AAFCS M33 computer.

3) The dc amplifier is an excellent isolation device.

b. Disadvantages.

1) A relatively high plate voltage is needed for its operation.

2) Direct coupling may cause instability.

3) To insure a quick response to a change in dc voltage input, the same gain from zero cycles per second to very high frequencies is necessary.

7. DC amplifiers are usually connected in an odd number of stages to obtain a polarity reversal (diag 213).

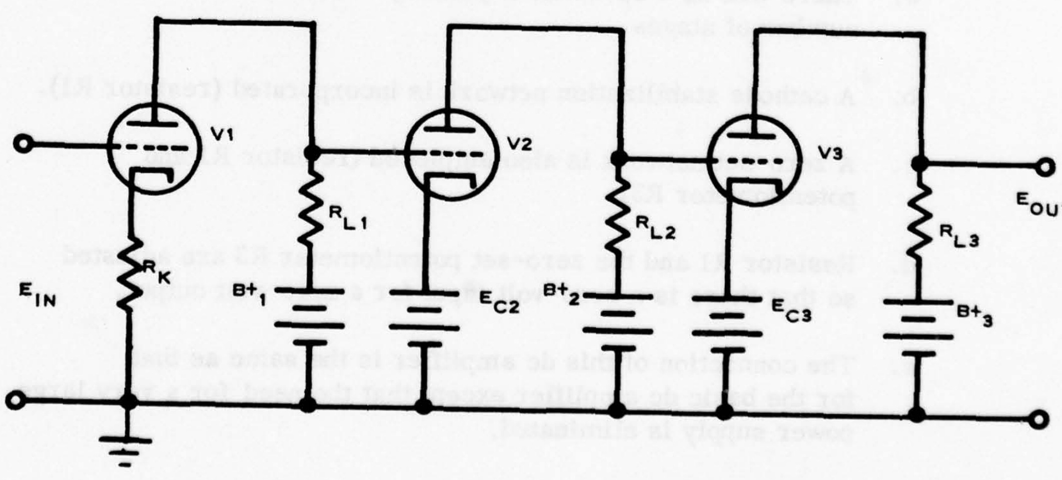


Diagram 213. Three-stage dc amplifier.

a. This reversal of polarity is desirable in many instances in computers.

b. Amplification will be determined by total number of stages.

8. The basic direct-coupled amplifiers are connected so that the plate of each stage is directly connected to the grid of the next stage.

a. There are no reactive elements in the amplifier.

b. There are a large number of battery supply voltages.

> INSTRUCTOR'S NOTE: Illustrate to students the major disadvantage of the amplifiers above: power-supply voltage must be successively greater with each additional stage.

9. The circuit that follows (diag 214) is a refinement of the basic dc amplifiers.

a. There will be a reversal of polarity because of the odd number of stages.

b. A cathode stabilization network is incorporated (resistor R1).

c. A zero-set network is also employed (resistor R1 and potentiometer R3).

d. Resistor R1 and the zero-set potentiometer R3 are adjusted so that there is a zero-volt input for a zero-volt output.

e. The connection of this dc amplifier is the same as that for the basic dc amplifier except that the need for a very large power supply is eliminated.

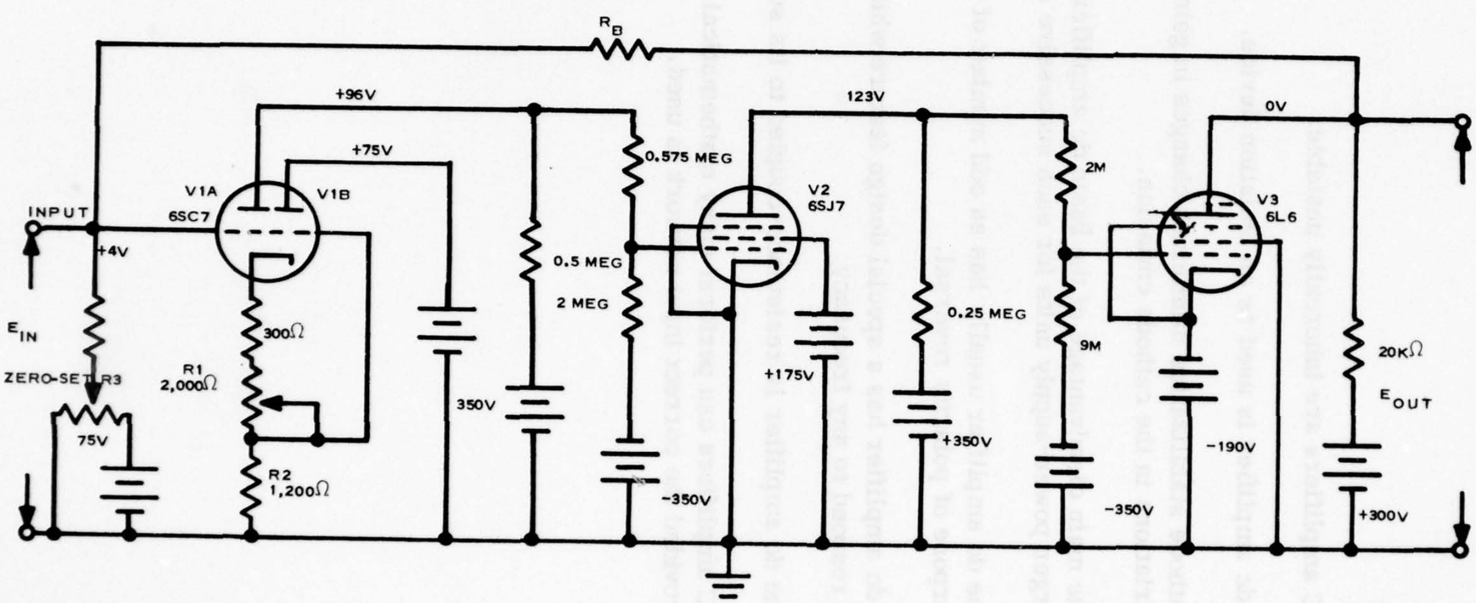


Diagram 214. DC amplifier schematic.

IF-39

SUMMARY:

1. DC amplifiers are inherently unstable.

2. A dc amplifier is used as an isolation device.

3. Cathode stabilization minimizes changes in gain caused by variations in the cathode emission.

4. The main disadvantage of the basic dc amplifier is the need for larger power-supply units for each successive stage.

5. The dc amplifier usually has an odd number of stages for the purpose of polarity reversal.

6. A dc amplifier has a special design feature which enables it to respond to any frequency.

7. The dc amplifier is resistance-coupled to its successive stages.

8. DC amplifiers can perform many mathematical calculations provided the correct input network is used.

LESSON PLAN

COINCIDENCE CIRCUITS

OBJECTIVE:

1. To present the purpose and operation of coincidence circuits, and
2. To discuss some of their uses in radar sets.

INTRODUCTION:

The coincidence circuit is one that is used very often in radar and radio equipment. This circuit is used to control the time at which certain actions take place. The coincidence tube is a selection device which is used throughout the AAFCS M33. Knowledge of its basic concepts will be a valuable aid to understanding this course.

PRESENTATION:

1. The basic coincidence circuit.

   a. The basic coincidence circuit is one in which at least two signals are simultaneously injected into a tube to produce an output.

   b. The coincidence tube is a pentode which is biased at suppressor grid cutoff and control grid cutoff.

   c. The bias on either grid will keep the tube cutoff even if one grid goes positive.

2. The following is a simplified diagram of a coincidence circuit (diag 215).

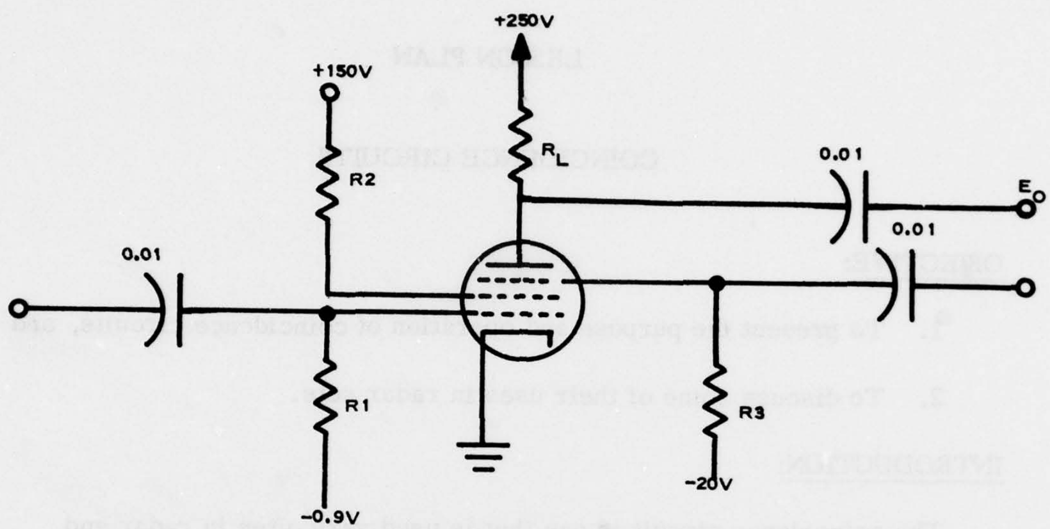


Diagram 215. Simplified coincidence circuit.

a. A voltage of positive nine volts or more must be placed on the control grid to overcome its bias.

b. The voltage placed on the suppressor grid must be of sufficient amplitude to overcome the -20v bias.

c. Both of the applied signals must reach the coincidence tube at the same instant in order for the tube to conduct.

d. The tube will conduct only for that amount of time that both signals are present at the tube.

e. An output will be produced only when the above conditions are met.

3. The circuit of diagram 216 is sometimes called a gating circuit.

4. This circuit is employed in the target designator system of the M33 fire control system.

a. The operation of the coincidence circuit in the M33 is the same as the basic coincidence circuit shown in diagram 215. The bias voltages used in the basic circuit, however, are not necessarily the same as those in the coincidence circuits in the M33.

b. The following is a description of one of the uses of the coincidence circuit in the M33 radar.

1) One of the items needed for display on the PPI's of the M33 is the electronic cross.

2) This display is shown in diagram 216.

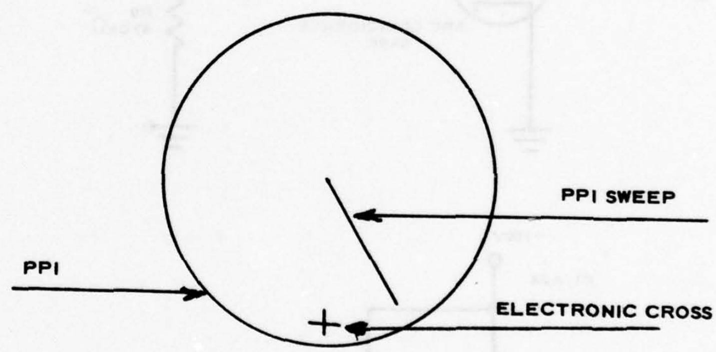


Diagram 216. Electronic cross on the PPI screen.

3) A coincidence tube is used to produce both the arc and also the radial line of the cross.

4) The circuit that produces the electronic cross is shown in diagram 217.

INSTRUCTOR'S NOTE: The components which are not mentioned in the discussion of the circuit in diagram 217 need not be explained.

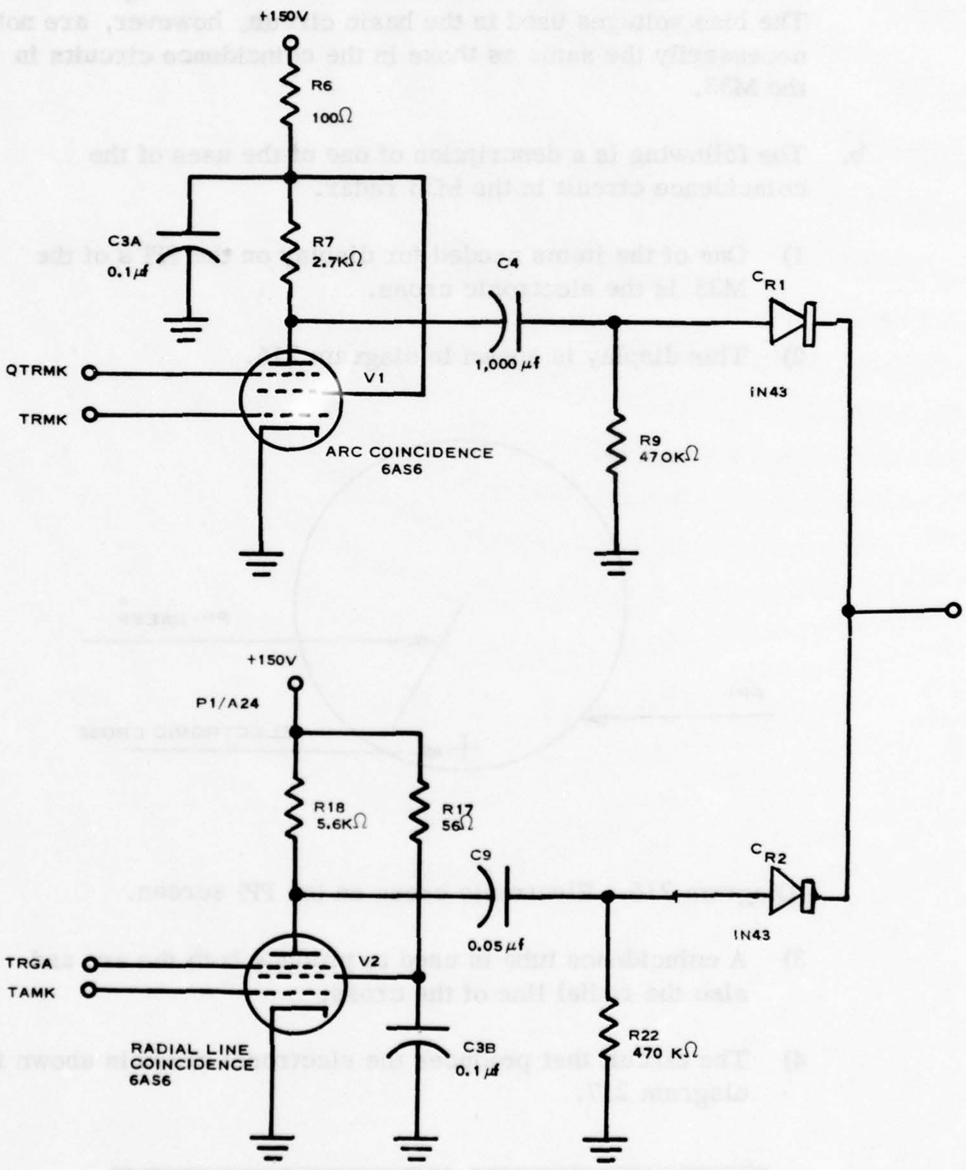


Diagram 217. Electronic-cross coincidence circuit.

a) Tube V1 is the coincidence tube that develops the arc of the electronic cross.

b) Tube V2 is the coincidence tube that develops the radial line of the electronic cross.

c) Since the operation of both tubes is the same, only the circuit of V1 will be discussed.

d) The inputs to tube V1 are as follows.

1. At pin 7, a positive waveform with the duration to 10° of antenna rotation appears once per revolution of the antenna as in diagram 218.

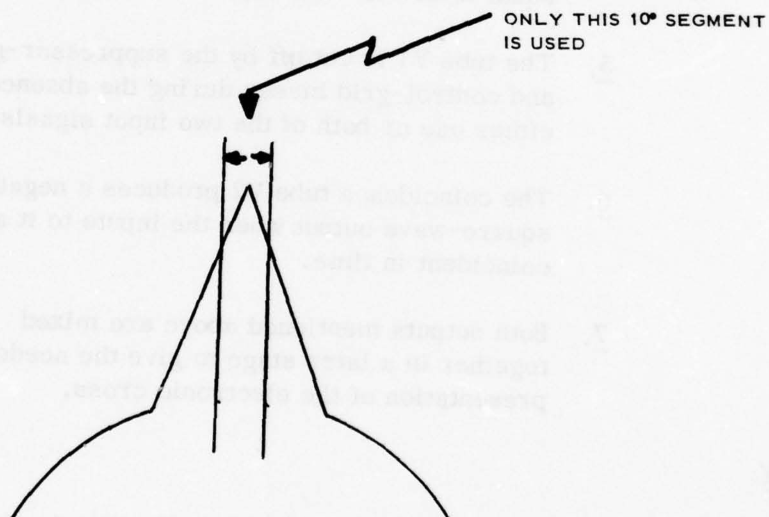


Diagram 218. Track azimuth gate.

2. At pin 1, a positive pulse with a duration of 0.5 microsecond, generated once each sweep, is applied. This pulse occurs at a range determined by the setting of the tracking radar. It appears as shown in diagram 219.

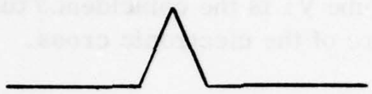


Diagram 219. Positive pulse.

3. Tube V1 will conduct only when these two signals are applied at the same time. This will happen at the time when the azimuths of the two radars coincide.

4. The output of tube V1 will be a sharp, negative pulse for this small duration of time (duration equal to 10° of rotation).

5. The tube V1 is cut off by the suppressor-grid and control-grid biases during the absence of either one or both of the two input signals.

6. The coincidence tube V2 produces a negative, square-wave output when the inputs to it are coincident in time.

7. Both outputs mentioned above are mixed together in a later stage to give the needed presentation of the electronic cross.

SUMMARY:

1. The coincidence circuit is so named because it conducts only when two signals appear at its grids in time coincidence.

2. For this reason, coincidence circuits are used in applications where it is desired to pass only certain portions of a continually generated wave-train.

   a. Usually a gating voltage appears at one grid only during the time the tube is desired to conduct.

   b. When the gate appears, the tube conducts and passes whatever is applied to the other grid.

   c. When the gating signal is over, the tube is cut off.

LESSON PLAN

CATHODE-RAY TUBES

OBJECTIVE:

To explain the operation and uses of cathode-ray tubes.

INTRODUCTION:

In the cathode-ray tube (CRT), a stream of electrons, called the cathode-ray beam, is emitted from an electron gun and flows along the axis of the tube. This beam impinges on the luminescent screen, or face of the tube, and causes a spot of light to appear on the screen.

By use of a set of sweep voltages, the spot of light can be caused to move back and forth on the face of the tube, thus establishing a sweep line. By the introduction of a proper voltage to one of the tube elements, the spot of light can be made to move vertically.

The combination of vertical and horizontal movement of the spot of light will resolve quickly varying voltages into an amplitude versus time relationship.

The cathode-ray tube can then be used to monitor waveforms of various shapes.

PRESENTATION:

1. Cathode.

   a. The source of electrons for the formation of the cathode-ray beam is an indirectly heated emitter usually composed of a small cylinder of nickel which is coated with some type of oxide emitter.

   b. Inside of the small nickel cylinder is a tungsten wire filament. As the filament heats up, heat will be conducted to the emitter

itself. The filament is wound in a spiral shape so that the magnetic field set up by the flow of current in half of the wire will be canceled by the field set up in the other half of the wire.

c. Electrons will be emitted from the end of the heated cathode and will be attracted by a positively charged anode. Most of the negatively charged electrons will strike the anode, but a few will go through a hole punched in the center of the anode (diag 220).

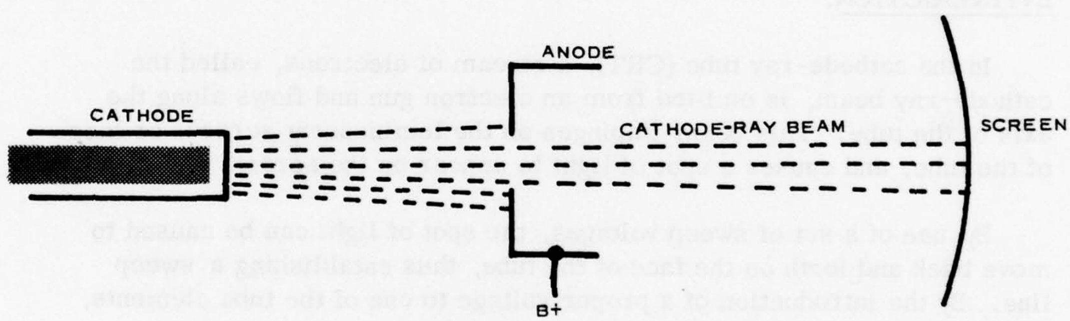


Diagram 220. Simple cathode-ray tube.

d. It can be seen that a high percentage of the emitted electrons will strike the anode and thereby cause an abnormally high current to flow in the external B+ power supply. For this reason, a focusing anode is used between the cathode and anode (diag 221).

e. The addition of the grid between the cathode and anode allows the number of electrons striking the anode to be controlled. The grid will usually be charged negatively with respect to the cathode.

f. After the beam passes through the anode, it is accelerated and further focused by additional anodes that are placed along the path of the cathode-ray beam (diag 222).

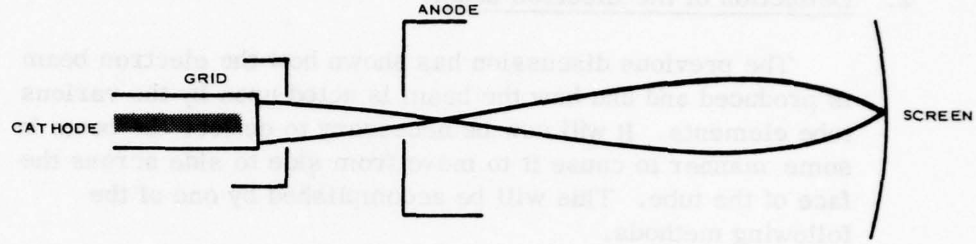


Diagram 221. Focused electron beam.

g. The accelerating anode is more positive than the first anode (focusing anode), and the focusing anode is more positive than the cathode. The use of several accelerating anodes will propel the stream of electrons at speeds in excess of 10,000 miles per second.

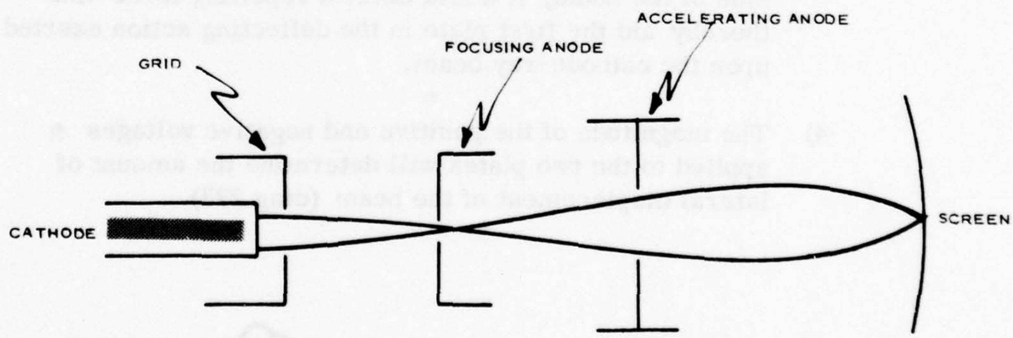


Diagram 222. Simplified cathode-ray tube.

> <u>INSTRUCTOR'S NOTE:</u> Explain how the configuration of the flux lines in the grid, the focusing anode, and the accelerating anode form the beam into a narrow pattern. Also explain how the aquadag coating is used as an accelerating anode.

2. Deflection of the Electron Beam.

The previous discussion has shown how the electron beam is produced and and how the beam is acted upon by the various tube elements. It will now be necessary to deflect the beam in some manner to cause it to move from side to side across the face of the tube. This will be accomplished by one of the following methods.

a. Electrostatic deflection.

1) Electrostatic deflection is based on the principle that like charges repel and unlike charges attract.

2) If a positively charged plate were placed near the narrow cathode-ray beam, the electrons flowing in the beam would be attracted to the positive charge on the plate.

3) If a negatively charged plate were placed on the opposite side of the beam, it would exert a repelling force and thereby aid the first plate in the deflecting action exerted upon the cathode-ray beam.

4) The magnitude of the positive and negative voltages applied to the two plates will determine the amount of lateral displacement of the beam (diag 223).

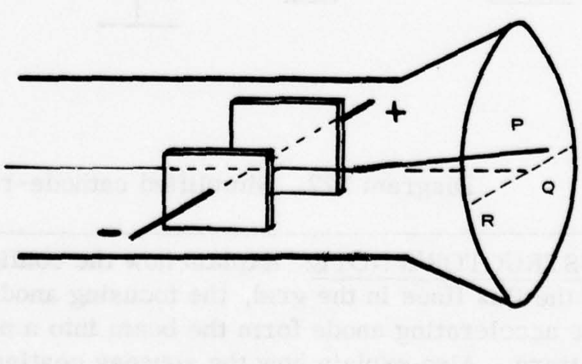


Diagram 223. Horizontal electrostatic deflection.

5) Plates placed above and below the electron beam will function in the manner previously described and will deflect the beam vertically (diag 224).

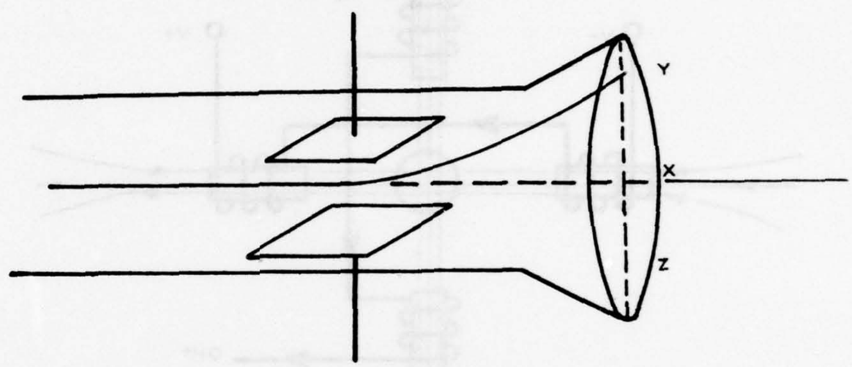


Diagram 224. Vertical electrostatic deflection.

6) Simultaneous application of ac voltages to both sets of plates will cause the electron beam to move in a direction which is the vector sum of the two applied voltages. The vector sum of the two voltages is dependent on the frequencies and relative phase relationships of the two signals.

b. Electromagnetic deflection.

1) The cathode-ray beam can also be deflected by the use of electromagnets mounted around the neck of the tube. The deflecting action of the electromagnets can be seen in diagram 225.

2) Currents flowing through both the vertical and horizontal deflection coils will set up corresponding magnetic fields that will act upon the electron beam in the same manner as the electrostatic deflection plates previously mentioned.

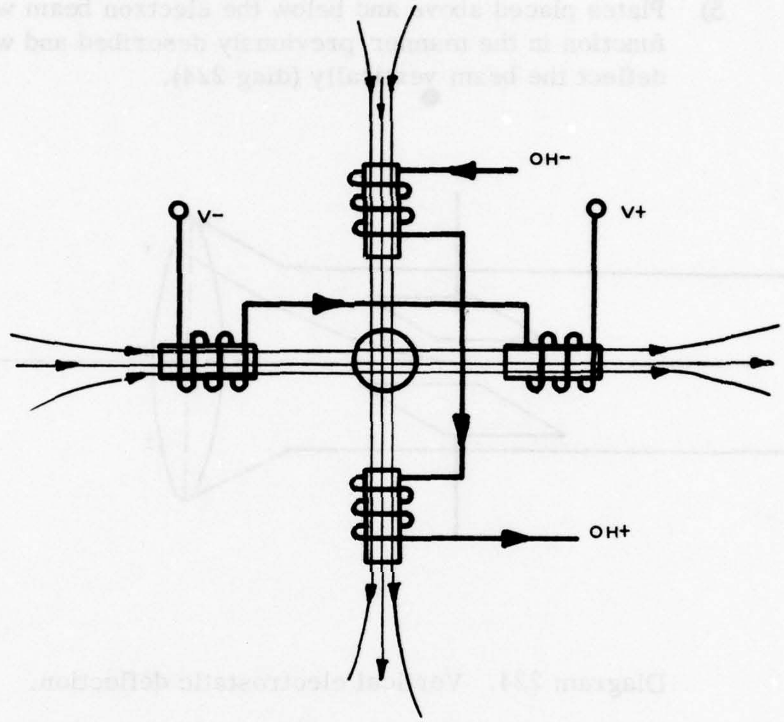


Diagram 225. Front view of electromagnetic deflection.

c. Comparison of electrostatic and eletromagnetic deflection methods.

1) The electron-gun structure of a cathode-ray tube utilizing electromagnetic deflection is simpler than the electron-gun structure of electrostatic type tubes. The electromagnetic tube has no deflecting electrodes inside the tube. The first anode of an electromagnetic tube serves to accelerate the electron beam. The second anode may be connected internally to the aquadag coating and accelerate the beam further.

2) Fewer internal anodes make for more rugged construction in the electromagnetic type tube.

3) Electromagnetic deflection, rather than electrostatic deflection, is used with large-screen tubes to achieve the necessary wide angle of deflection, better focusing, and improved linearity.

4) The greater deflection angles achieved allow large, electromagnetically deflected tubes to have relatively short, over-all tube length, making possible a reduction in size of the equipment in which the tube is used.

5) A definite advantage of the electrostatic tube is that it requires little or no deflection current or power. This reduces the complexity of the circuits that supply the tube and allows the use of simple and inexpensive power supplies.

3. Focusing of the Electron Beam.

a. The simplified cathode-ray tube discussed at the beginning of this lesson was focused by the first anode (focusing anode) and the successive accelerating anodes. The amount of focusing action is determined by the potential on these elements. When this type of focusing is used, the tube is said to be electrostatically focused.

b. Focusing of the cathode-ray beam can be accomplished by an electromagnetic field developed by a coil wound around a soft iron ring which is placed around the neck of the tube The inner side of this circular coil is grooved to form an air gap (diag 226).

c. An adjustable direct current through the winding sets up a strong magnetic field within the iron ring except for the area about the air gap. Here the field may escape in a configuration somewhat as shown within the neck of the tube and about the electron beam (diag 226). Electrons moving along the exact center of the tube will experience no deflection since they move parallel to the magnetic field at all times. All other electrons are diverging as

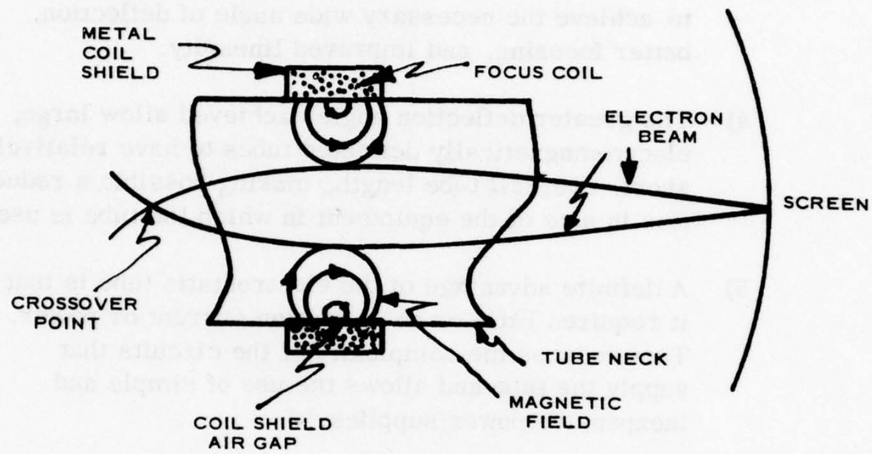


Diagram 226. Electromagnetic focusing.

they leave the crossover point. As the diverging electrons cross the magnetic field of the focus coil, they constitute a current flowing in that direction.

1) In accordance with the right hand rule, the magnetic field will exert a force on the electrons causing them to move toward the center of the tube.

   a) As the high-velocity electrons move forward through the focusing coil, the force of the magnetic field causes them to move in a helical manner similar to the thread on a wood screw.

   b) All the electrons that pass through this field are caused to move in this spiral path.

   c) Those electrons that are far from the axis follow a path that makes them meet the electrons passing along the axis at the focal point on the screen of the tube.

d) In diagram 227, the electron paths are shown as lines in the plane of the paper, rather than in their true helical paths, for the sake of clarity.

2) The focal point of the electron beam may be made to appear on the screen as a sharply defined point by adjusting the strength of the magnetic field of the focus coil through varying the magnitude of the dc current flowing through it.

a) The focus coil is usually mounted so that it can be tilted about the axis of the tube.

b) This enables the focal point of the electron beam to be centered on the face of the screen.

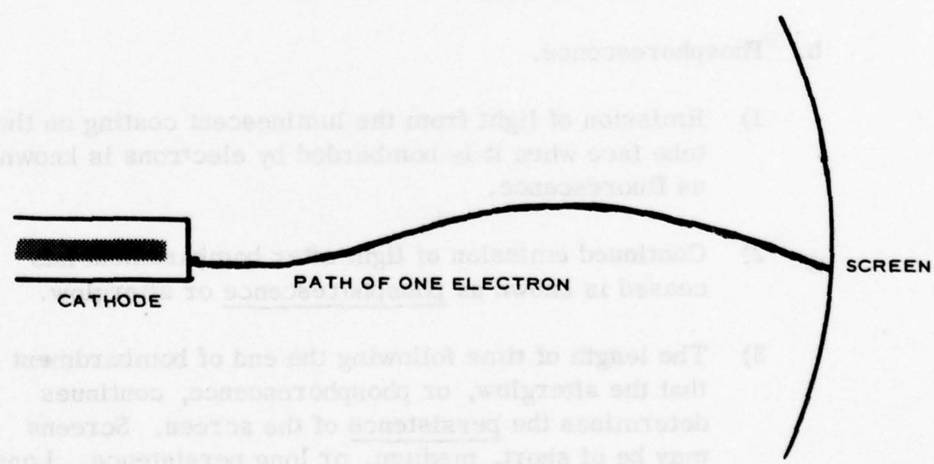


Diagram 227. Curvature of electron path.

4. Cathode-Ray Tube Screens.

a. Screen materials.

1) The inside face of the tube screen is coated with a luminescent material which will emit light rays when bombarded by a stream of high-velocity electrons.

2) Thickness of the material is approximately 0.002 millimeter.

3) It is applied by spraying, dusting, or settling from a liquid.

4) Materials commonly used for screens are willemite, which gives off a predominantly green light, and zinc oxide, which emits a blue light. A mixture of zinc sulphide and cadmium zinc sulphide is also often used and gives almost white light. Other colors are available for specific purposes if needed.

b. Phosphorescence.

1) Emission of light from the luminescent coating on the tube face when it is bombarded by electrons is known as fluorescence.

2) Continued emission of light after bombardment has ceased is known as phosphorescence or afterglow.

3) The length of time following the end of bombardment that the afterglow, or phosphorescence, continues determines the persistence of the screen. Screens may be of short, medium, or long persistence. Long persistence screens are usually used to observe the waveforms of low-frequency, periodic phenomena, or nonrepeating functions. Short persistence screens are commonly used in television and in oscilloscopes.

4) The amount of light emitted by a particular screen is dependent on the speed with which the electrons strike it and upon the number of electrons in the beam. Electron speed is controlled by the accelerating electrode voltages, and the number of electrons emitted is determined by the grid potential.

5) Continuous impact of the beam of electrons upon a single spot on the screen will reduce the sensitivity or light-emitting qualities of that particular point. Eventually, this may result in a dead spot on the screen from which no light will be emitted. This condition may be avoided by adjusting the tube electrode voltages for the lowest usable brilliance and by frequent repositioning of the spot or pattern.

6) Reflection of room light from the tube face may cause difficulty in seeing the pattern. This condition may be reduced by use of a light filter over the tube face to absorb the external reflections. Use of a tubular extension around and in front of the screen will also reduce glare from room light.

INSTRUCTOR'S NOTE: Explain the index such as P4, P7, etc., that is used to express the persistency of a screen. Also, explain the various types of presentation used with CRT's: A-scan, B-scan, PPI, J-scan, etc.

SUMMARY:

1. The cathode-ray tube is a special type of electron tube which permits the visual observation of electrical signals. It may be incorporated into an oscilloscope for use as a test instrument or it may be the display device for a radar system or a television receiver.

2. The cathode-ray tube always includes an electron gun for producing a stream of electrons, a grid for controlling the intensity of the electron beam, and a luminescent screen for converting the impinging electron beam into visible light.

3. Such a tube must also have either an internal or external means of focusing and also a method for sweeping or deflecting the beam at regular time intervals and in accordance with the monitored signal.

LESSON PLAN

RELAYS

OBJECTIVE:

1. To present the uses of relays,
2. To discuss the make-up and operation of relays, and
3. To demonstrate some uses of relays.

INTRODUCTION:

Whenever an electrical circuit is employed, there must be at least one method for controlling the flow of current to it. The action of energizing or deenergizing a circuit is accomplished by power control devices. Modern radar and fire control equipment employs a considerable number of control devices in order to function properly. The control device most used in radar and fire control equipment is the relay.

PRESENTATION:

1. Relays may be used as:

    a. Timing devices,

    b. Protective devices,

    c. Signal-carrying devices,

    d. Control devices, etc.

2. Some relay principles are:

    a. A relay is a switch which is operated electromagnetically,

b. A relay is designed to open or close a circuit when current flows through it, and

c. A relay can be energized by an ac or dc source.

3. The main components of relays are:

a. An iron-core coil which serves as an electromagnet, and

b. One set, or many sets, of contacts which are nothing but metallic arms that can be moved by the magnetic field of the coil.

4. The general operation of relays is explained below (diag 228).

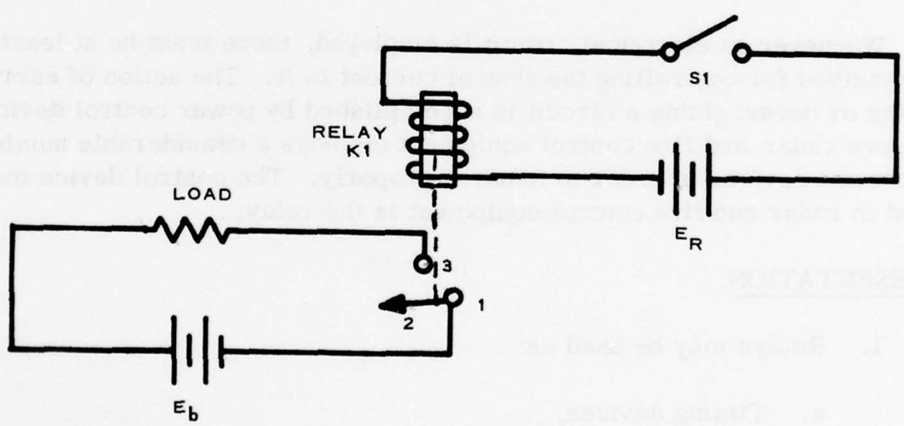


Diagram 228. Externally operated relay.

a. Closing the switch S1 allows current to flow through the coil of the relay.

b. Current flowing through the coil creates a magnetic field around the coil of the relay. This is called <u>energizing</u> the relay.

c. The magnetic field attracts contact 2 upward, completing the circuit between points 1 and 3.

d. Completion of the circuit allows voltage to be applied to the load.

e. The circuit relay explained above is a normally open type.

> INSTRUCTOR'S NOTE: There are relay circuits which are of the normally closed type. Explain, if necessary, the operation of the normally closed relay circuit.

5. The disadvantages of ac relays are as follows:

   a. The contacts of ac relays chatter or vibrate, and

   b. AC relays must be made rather heavy.

6. Relays are normally designed for operation on standard voltage sources, such as:

   a. 6 volts,

   b. 12 volts,

   c. 28 volts,

   d. 30 volts, and

   e. 115 volts.

7. Some uses of relays are:

   a. A circuit-control relay is used when the circuit functions become so numerous that operating switches for each would be too complicated and time-consuming. Radar sets use control relays to a great extent (diag 229).

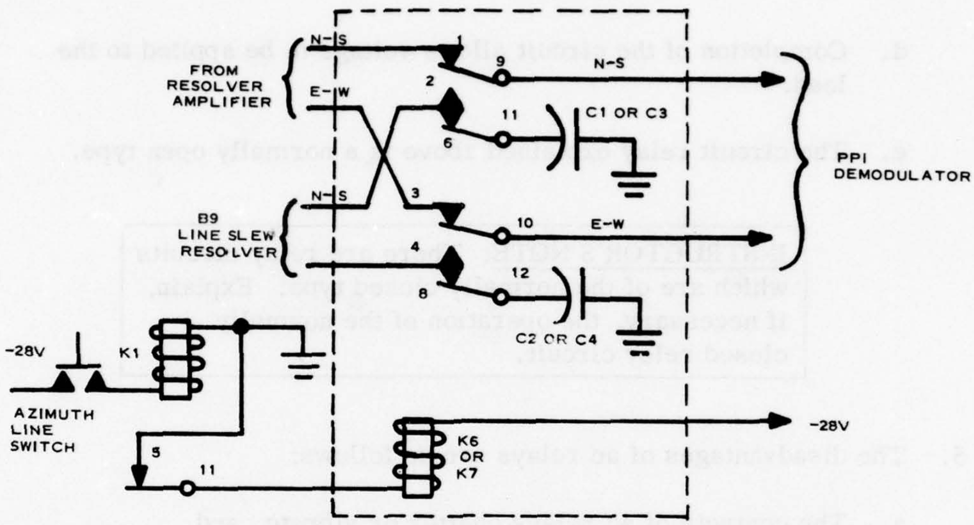


Diagram 229. Circuit-control relay simplified schematic.

INSTRUCTOR'S NOTE: Explain the action of the relays and contacts of the circuit shown above.

b. A protective relay is designed so that it will break a circuit when the current through it reaches a predetermined limit.

1) A protective relay is used when an overload or underload occurs in a circuit.

2) It is most commonly used in power supplies.

3) An example of this is shown in diagram 230.

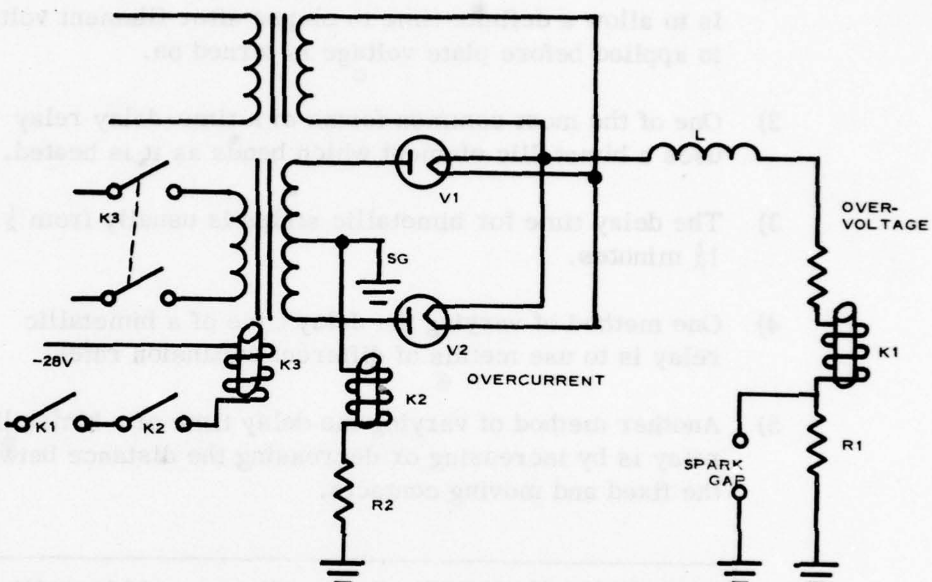


Diagram 230. Power supply protective relay system.

a) The relay K1 will energize when the voltage produced by the power supply exceeds a certain value.

b) The relay K2 will energize when the current drain on the power supply exceeds a certain value.

c) Energizing either relay will make the equipment inoperative.

Note: These relays are the normally closed type.

c. The time-delay relay is used to provide a time interval between separate operations.

1) The most common use of the time-delay relay in radar is to allow a definite time to elapse after filament voltage is applied before plate voltage is turned on.

2) One of the most common forms of a time-delay relay uses a bimetallic element which bends as it is heated.

3) The delay time for bimetallic strips is usually from $\frac{1}{2}$ to $1\frac{1}{2}$ minutes.

4) One method of varying the delay time of a bimetallic relay is to use metals of different expansion rates.

5) Another method of varying the delay time of a bimetallic relay is by increasing or decreasing the distance between the fixed and moving contacts.

INSTRUCTOR'S NOTE: Draw a diagram of bimetallic relays showing the different types of metals. Present the basic operation of the relays.

SUMMARY:

1. Relays are one of the most simple and easy to understand pieces of equipment with which the student will come into contact during the succeeding study of electronics, but the mere simplicity of the relay and its operation does not detract from the important position it holds as one of science's most adaptable and useful tools.

2. Relays can be used to save countless dollars worth of valuable equipment. They can be used to energize or deenergize many circuits at the flick of a finger several miles away.

3. The design of all types of relays has been refined to such a degree that relays can be expected to operate trouble free for millions of operations in tropical heat and in arctic cold.

LESSON PLAN

ONE-SHOT MULTIVIBRATOR

OBJECTIVE:

To explain the operation of the one-shot multivibrator.

INTRODUCTION:

The multivibrator is a form of relaxation oscillator. The simplest type is the one-shot multivibrator. In addition, there are continuous or free-running and driven multivibrator types. The frequency of operation of the driven multivibrator is controlled by a synchronizing, or triggering, voltage applied from an outside source. The output voltage of a multivibrator usually has a rectangular waveform, and the frequency may range from about 1 cycle per minute to 100 kilocycles per second.

PRESENTATION:

1. In certain applications, it is required that a multivibrator be quiescent until its action is initiated by a pulse of voltage from an external source. The multivibrator goes through one cycle of operation, after which it reverts to the original quiescent condition in which it remains until triggered by another pulse. Such a circuit is called a one-shot multivibrator. As shown in diagram 231, the circuit consists, essentially, of a two-stage resistance-capacitance coupled amplifier with tube V1 normally cutoff and tube V2 normally conducting. The quiescent condition of the circuit is established by the arrangement for biasing the tubes. Tube V2 normally conducts heavily because it has zero bias since its grid is connected to the cathode through resistor R2; but the resulting voltage drop across R_k biases V1 below cutoff. When V2 is not conducting, V1 cannot be cut off by the self-bias developed across R_k.

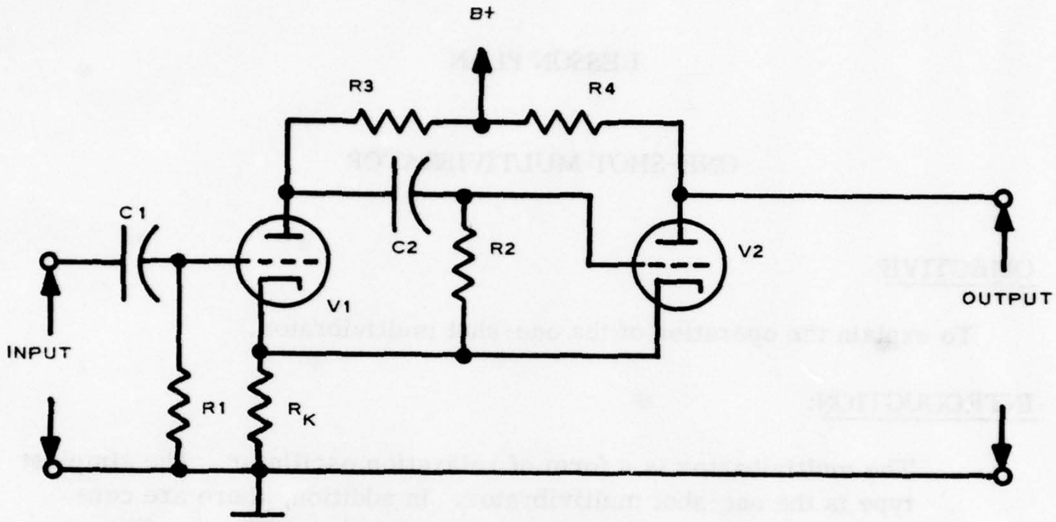


Diagram 231. One-shot multivibrator.

2. Circuit action of a one-shot multivibrator.

   a. V2 is conducting heavily because its grid is at cathode potential at time X in diagram 232.

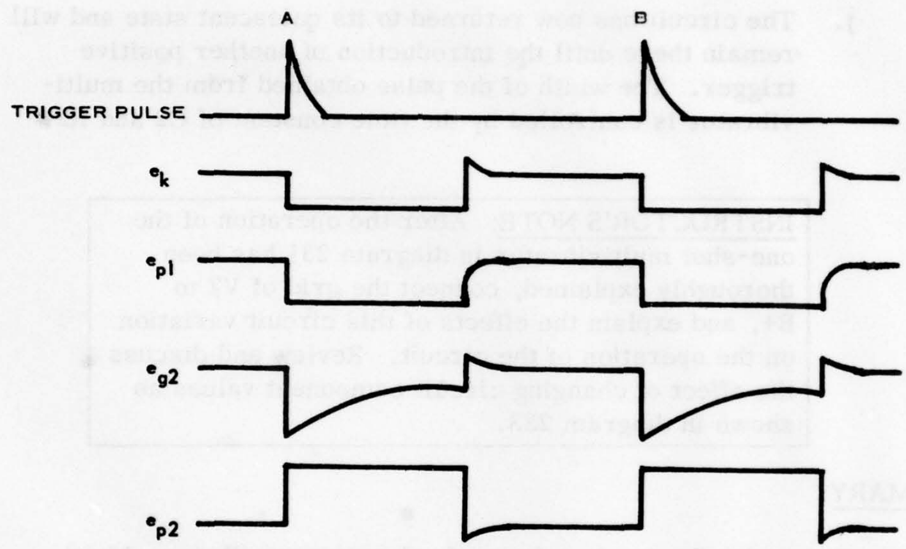
   b. V1 is cut off by the voltage drop produced across R_k by I_{p2}, the plate current of V2 (diag 231).

   c. The introduction of a positive-going timing spike to the grid of V1 will cause tube V1 to conduct.

   d. As V1 conducts, the voltage drop at its plate is coupled to the grid of V2, making it negative.

   e. As V2 conducts less, the current through R_k decreases. As a result, the cathode of V1 goes negative, and V1 conducts more.

   f. When V1 conducts more, its plate voltage drops more, and the drop is also coupled to the grid of V2, causing V2 to conduct even less.



e_k = VOLTAGE ACROSS CATHODE RESISTOR.
e_{p1} = VOLTAGE AT PLATE OF V1.
e_{g2} = VOLTAGE AT GRID OF V2.
e_{p2} = VOLTAGE AT PLATE OF V3.

Diagram 232. Waveforms associated with one-shot multivibrator.

g. **The action is cumulative and ends when V1 is conducting and V2 is cutoff. The switchover is almost instantaneous.**

h. **The multivibrator will remain in the condition described until capacitor C2 has discharged to the lowered level of the plate voltage on V1. As the capacitor discharges, the voltage at the grid of V2 rises until V2 begins to conduct.**

i. When V2 conducts, its plate current flowing through R_k will raise the cathode potential of V1 until this stage is cut off.

j. The circuit has now returned to its quiescent state and will remain there until the introduction of another positive trigger. The width of the pulse obtained from the multivibrator is controlled by the time constant of C2 and R2.

INSTRUCTOR'S NOTE: After the operation of the one-shot multivibrator in diagram 231 has been thoroughly explained, connect the grid of V2 to B+, and explain the effects of this circuit variation on the operation of the circuit. Review and discuss the effect of changing circuit component values as shown in diagram 233.

SUMMARY:

1. The multivibrator is a form of relaxation oscillator. Multivibrators may be designed as continuous (free-running) oscillators or as driven oscillators (one-shot) whose operation and frequency are controlled by a synchronizing or triggering pulse.

2. A multivibrator that goes through only one cycle of operation when properly triggered is called a one-shot multivibrator.

3. A one-shot multivibrator with a positive, grid return provides more accurate timing than the circuit of diagram 231. This results from the fact that the discharge curve for the positive grid multivibrator strikes cutoff at a more vertical angle. This causes the tube V2 to conduct at precisely the same point each cycle.

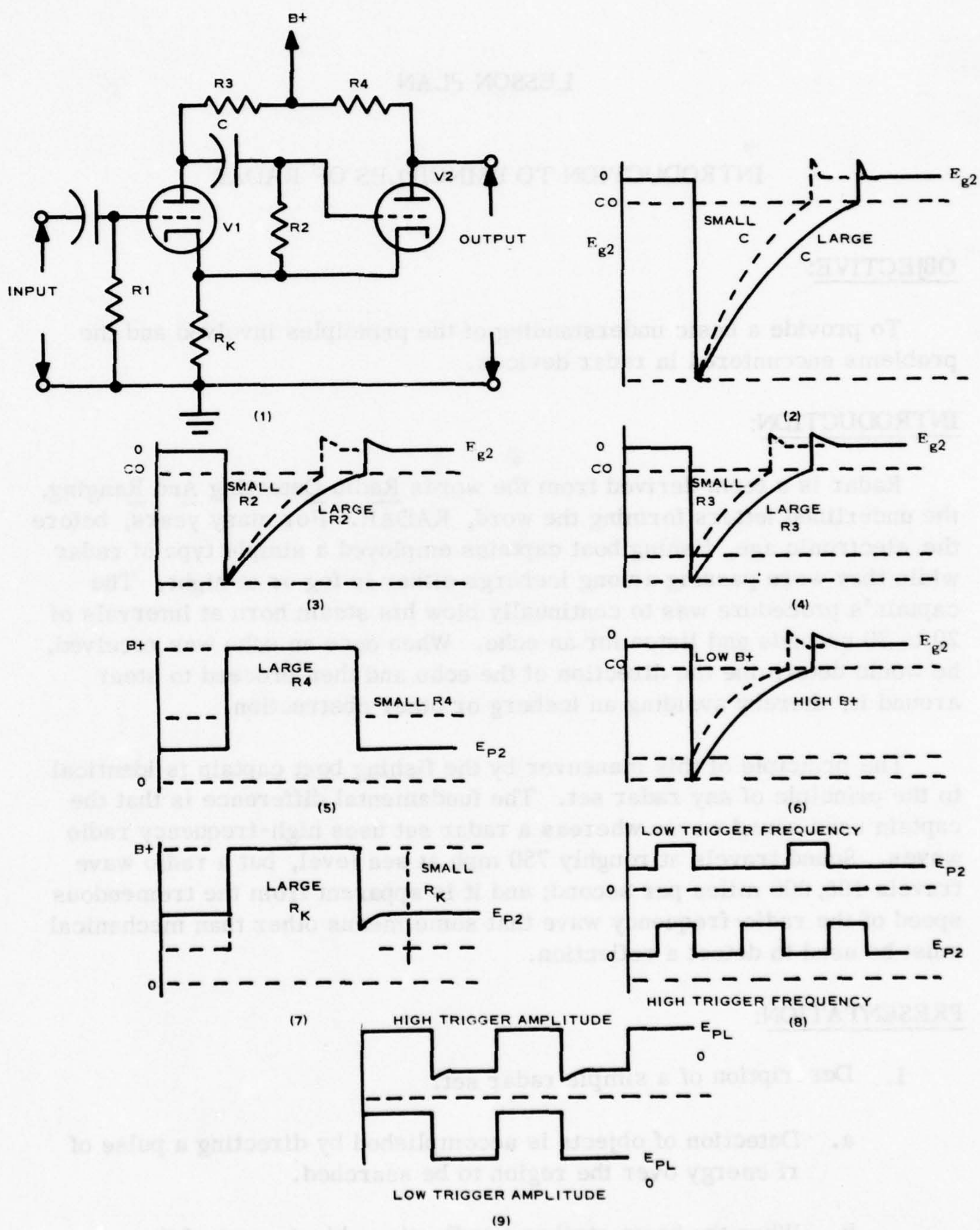


Diagram 233. Effect of changing circuit component values.

LESSON PLAN

INTRODUCTION TO PRINCIPLES OF RADAR

OBJECTIVE:

To provide a basic understanding of the principles involved and the problems encountered in radar devices.

INTRODUCTION:

Radar is a term derived from the words Radio Detecting And Ranging, the underlined letters forming the word, RADAR. For many years, before the electronic age, fishing boat captains employed a simple type of radar while they were passing among icebergs either in fog or at night. The captain's procedure was to continually blow his steam horn at intervals of 20 to 30 seconds and listen for an echo. When once an echo was received, he would determine the direction of the echo and then proceed to steer around it, thereby avoiding an iceberg or other obstruction.

The principle of this maneuver by the fishing boat captain is identical to the principle of any radar set. The fundamental difference is that the captain used sound waves whereas a radar set uses high-frequency radio waves. Sound travels at roughly 750 mph at sea level, but a radio wave travels 186,000 miles per second; and it is apparent from the tremendous speed of the radio-frequency wave that some means other than mechanical must be used to detect a reflection.

PRESENTATION:

1. Description of a simple radar set.

   a. Detection of objects is accomplished by directing a pulse of rf energy over the region to be searched.

   b. When the beam strikes a reflecting object, part of the transmitted energy is reflected.

c. A very small part of the reflected energy is returned to the directing antenna during the periods between transmitted pulses.

d. A very sensitive receiver is used to detect the echo from the reflecting object or target.

e. An accurate estimation of the range to the target can be obtained since rf travels at a constant velocity of 328 yards per microsecond.

INSTRUCTOR'S NOTE: Explain the reasons for measuring time in microseconds where rf is concerned, and explain the meaning of the expression: 1 microsecond = 164 yards radar range.

f. Determination of a target's direction can be made since the transmitting antenna is highly directional.

g. The term "pulse radar" is used to designate any system in which the transmitter is turned on for a specified length of time (usually only a few microseconds) and in which the reception of targets is accomplished during the waiting period between pulses.

2. Applications of radar.

a. Search.

1) Radar can be of extreme importance in the initial location of any enemy ground force and also in providing a continuous flow of information regarding the disposition and movement of the enemy forces.

2) The location of aircraft targets differs from the detection of ground targets in that aircraft are comparatively small targets and fly at great speeds. The

speed of aircraft necessitates the use of early warning radar by which the presence of aircraft can be detected at great ranges, thereby furnishing sufficient time in which to take effective action and retaliatory measures.

3) The location of surface naval vessels involves only the determination of range and azimuth. Surface search radar is used largely to provide initial warning of the presence of such targets and to keep track of their movements.

b. Fire control.

1) Fire control requires accurate information on range, azimuth, and elevation. The system must be linked very closely with the guns or missile to be controlled because of the very short time the aircraft is within range.

2) The problem of fire control against naval vessels is much simpler because of the slower moving targets. Fire control systems for use against surface targets measure range and azimuth only but to a high degree of accuracy.

3. Radar types.

a. Continuous-wave (CW) method.

1) This method makes use of the doppler effect.

> INSTRUCTOR'S NOTE: Briefly explain the doppler effect.

2) The transmitter radiates a continuous beam at a fixed frequency.

3) The frequency difference between the transmitted beam and the reflected signal can be used to determine the presence and speed of a target.

4) This method works very well with moving targets but is almost useless with stationary targets.

b. Frequency-modulation (FM) method.

1) In this method the frequency of the transmitted energy is continually and periodically varied over a specified band.

2) The frequency radiated by the antenna differs from the frequency reflected from the target.

3) The amount of frequency deviation is a function of the range of the target.

4) Because of the doppler effect, a moving target will introduce a phase shift which will affect the range accuracy of this type of radar.

c. Pulse-modulation method.

1) In this method the transmitter is caused to radiate rf energy for a short period of time.

2) During the time between rf bursts (pulses), the receiver is allowed to receive any echoes that may be reflected from targets.

3) The determination of range is made by measuring the time required for rf to reach the target and return to the radar.

4. The AAFCS M33 is a pulse-modulated radar; therefore, in the discussion to follow, only this type of radar will be considered.

5. Determination of range.

   a. RF energy, once it has been radiated into space, will travel with a constant velocity.

   b. When it strikes a target, there is no loss in time, merely a reversal or change in direction.

   c. The velocity of the rf energy is the same as that of light (186, 000 miles per second, or 328 yards per microsecond).

   Example: Assume that a target exists 32, 800 yards from a a radar set (diag 234).

   If a pulse of rf energy leaves the radar antenna, it will travel at the rate of 328 yards per microsecond until it reaches the target. When the target is reached, the rf energy will have traveled 32, 800 yards; therefore, a period of 100 microseconds has elapsed. It will then be reflected and begin traveling toward the transmitting antenna which is 32, 800 yards away, and 100 microseconds will be needed for the return trip. By the time the echo is received at the radar, a period of 200 microsceonds has elapsed. Since the distance to the target is 32, 800 yards, it follows that in 1 microsecond the rf can make a round trip to a target 164 yards away; $\left(\frac{32,800}{200}\right)$ or, for purposes of radar ranging, we can say that 1 microsecond equals 164 yards of radar range.

6. Time measurement.

   a. An extremely precise method of time measurement is necessary in radar since the measurement is being made in microseconds.

   b. The cathode-ray tube is well suited to displaying the extremely precise time relations involved. Its sweep can be used as a time scale which will allow the tube to display information on a "target versus time" basis.

c. Diagram 234 shows how a return or reflection from a target is presented on a cathode-ray tube. It will also be noticed in the hypothetical example that the return from the target occurs two inches along the CRT sweep from the transmitted pulse. Using this scope, therefore, we know that any target occurring 2 inches from 0 time is at a range of 32, 800 yards. Likewise, a target 1 inch from 0 time is at a range of 16, 400 yards, and so forth. We can then calibrate the baseline of the CRT in yards (diag 235).

d. After the baseline of the CRT has been calibrated in yards, the range of any displayed target can be estimated.

7. Determination of bearing or azimuth.

a. The directional characteristics of antennas are utilized in the determination of the angular position of a target with respect to true north (azimuth) or to the heading of the vessel on which the radar is placed (bearing).

INSTRUCTOR'S NOTE: Explain the factors which affect the directivity of a radiating antenna.

b. If a radiating antenna is pointed directly at a target, the reflection from that target will be maximum.

c. The directional properties of the antenna determine how much the antenna can miss the target and still get a reflection.

d. By positioning the antenna until a point of maximum signal strength is obtained, the azimuth and elevation of the target can be read off scales which are positioned by the antenna itself.

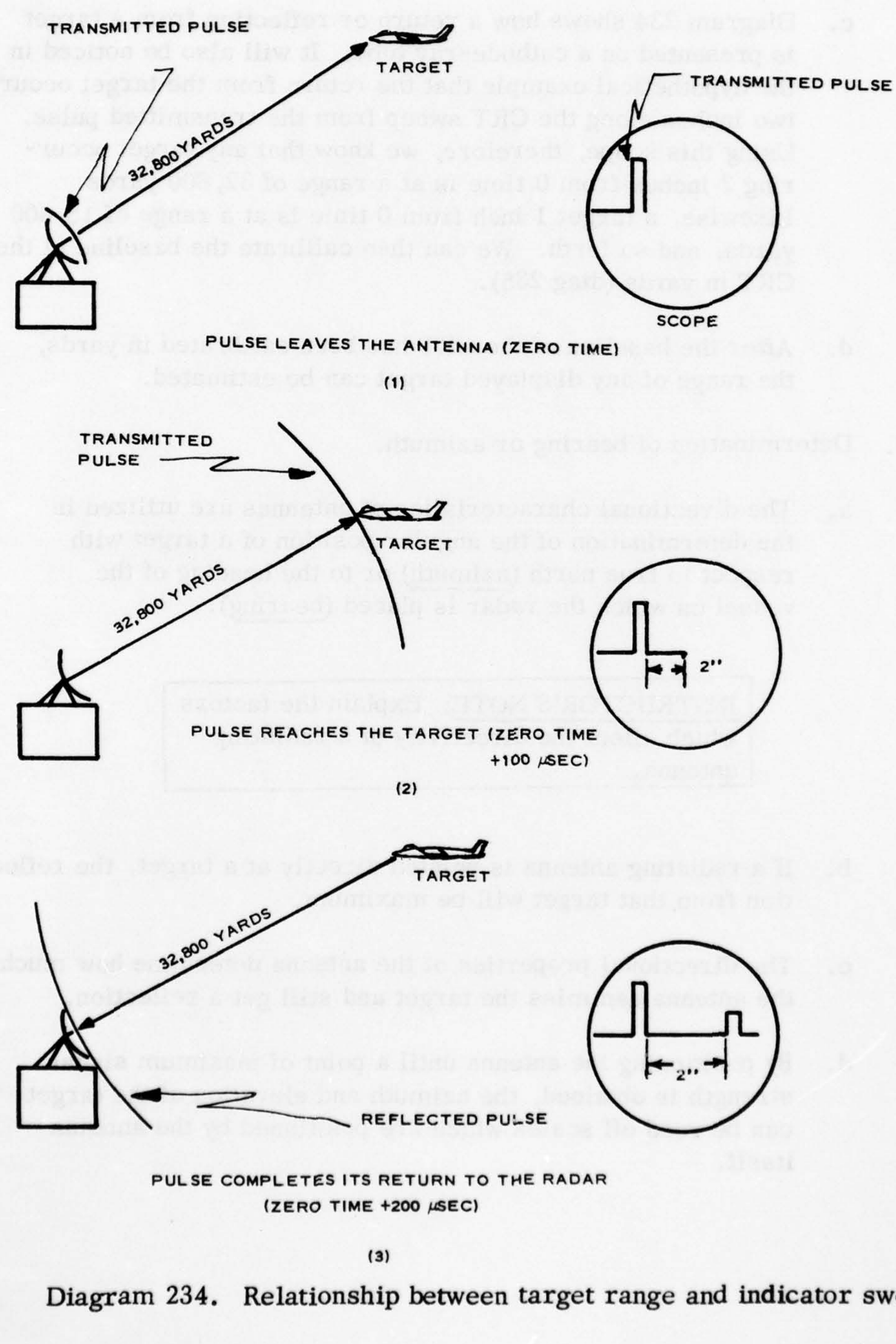


Diagram 234. Relationship between target range and indicator sweep.

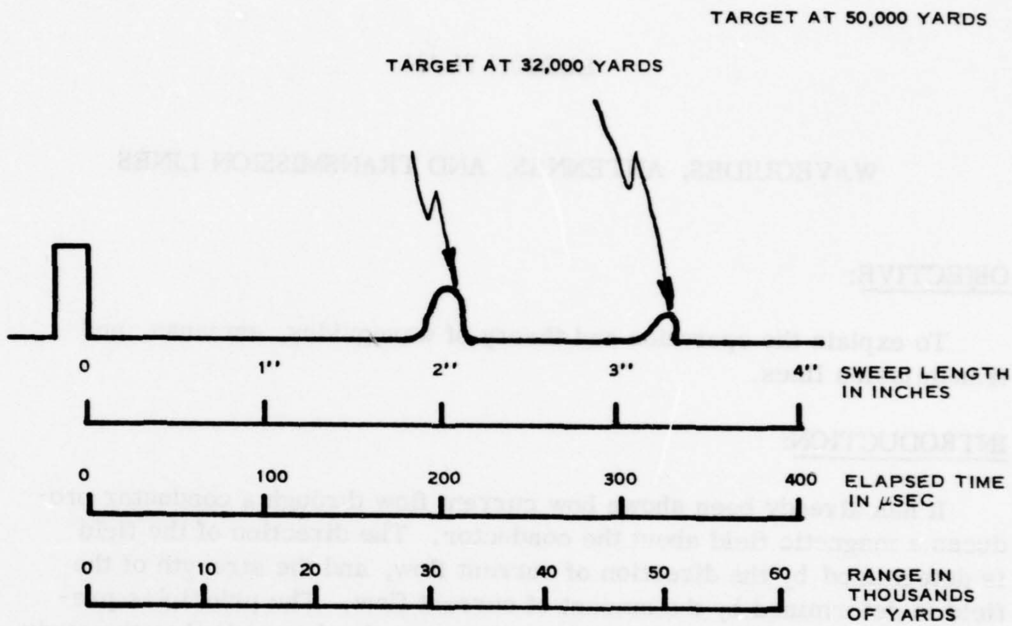


Diagram 235. Calibration of cathode-ray tube.

SUMMARY:

1. RF energy travels at 186,000 miles per second, or 328 yards per microsecond.

2. Radar range for 1 microsecond is 164 yards.

3. A pulse-type radar transmits for a short time and then has a waiting period in which reflections can be received before the next transmission pulse. (The AAFCS M33 is a pulse-type radar.)

4. The time measurement in a radar must be extremely precise.

5. Cathode-ray tubes are very well suited to the display of the precise time measurement required in a radar.

LESSON PLAN

WAVEGUIDES, ANTENNAS, AND TRANSMISSION LINES

OBJECTIVE:

To explain the operation and theory of waveguides, antennas, and transmission lines.

INTRODUCTION:

It has already been shown how current flow through a conductor produces a magnetic field about the conductor. The direction of the field is determined by the direction of current flow, and the strength of the field is determined by the amount of current flow. The principles previously learned in the study of magnetism can also be applied to the study of antennas.

PRESENTATION:

1. Assume that two wires are attached to the terminals on a high-frequency generator, and the lengths of the wires are one-quarter wavelength of the generator frequency (diag 236).

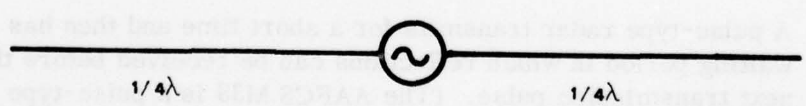


Diagram 236. Dipole antenna.

INSTRUCTOR'S NOTE: Explain that if each wire is one-quarter wavelength, the outside ends of the wires will be separated by one-half wavelength, and that with this arrangement we have an antenna known as a dipole.

2. At a given time the right side of the generator will be positive and the left side negative. Consider, now, the action that takes place in this condition.

INSTRUCTOR'S NOTE: Make the appropriate drawing on the blackboard.

a. Current flows through the right wire toward the positive terminal.

b. Current also flows from the negative terminal toward the end of the left wire. Once the current reaches the end of the left wire, there is no place for it to go.

c. Therefore, current flow at the end of the wire is zero, and at the center of the two wires current flow is maximum.

d. The same action occurs when the left terminal of the generator goes positive, except that the current flows from left to right (diag 237).

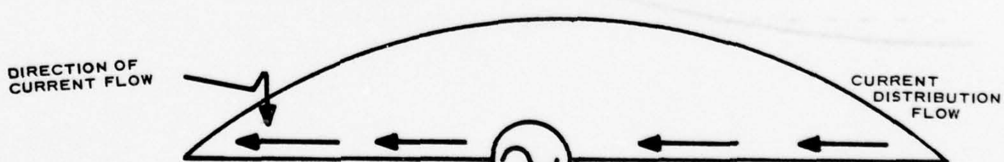


Diagram 237. Current distribution on a dipole antenna.

e. One-quarter cycle after the right generator terminal goes positive, the generator develops maximum voltage.

INSTRUCTOR'S NOTE: Explain the last statement.

f. Current starts to flow at the exact time that the right terminal becomes positive; therefore, one-quarter cycle later, when the generator is developing maximum voltage, no current will flow through the generator since all the free electrons have already been transferred from the right wire to the left wire.

> INSTRUCTOR'S NOTE: Explain that, even though no current flows at the ends of the wire, maximum voltage exists at the ends of the wire.

g. The current distribution along the dipole when the generator develops maximum voltage appears as follows (diag 238).

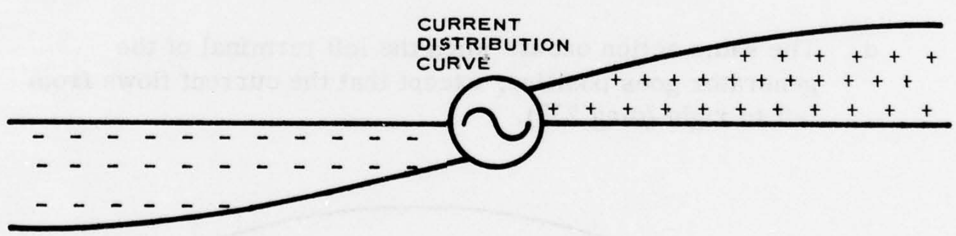


Diagram 238. Current distribution on dipole with maximum voltage at the generator.

> INSTRUCTOR'S NOTE: Review the action of the dipole. Stress the fact that the voltage and current distribution are 90° out of phase and that any magnetic field (H field) developed by the current flow is 90° out of phase with the field caused by the positive or negative charges (E field).

3. The magnetic and electric fields caused by the current flow through the wires and the difference in potential between the ends of the wires constitute the induction field about the antenna. The amplitude of the induction field varies inversely as the square of the distance from the antenna. As a result, its effect is quite local.

4. Radiation field.

   a. For the sake of simplicity, we can delete the generator in future drawings. But its effect, namely the alternating voltage, is still present. The following conditions exist about the dipole antenna when one side is positively charged and the opposite negatively charged.

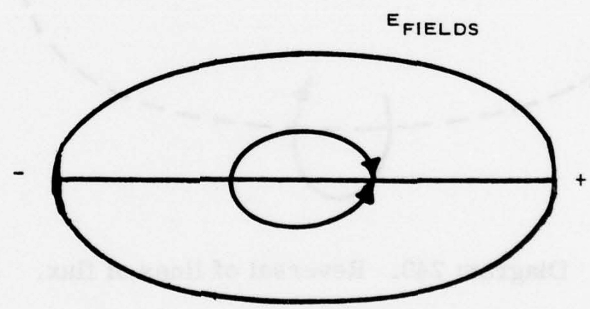


Diagram 239. E fields surrounding a dipole.

1) When the right side of the line is positively charged and the left negatively charged, an electric field exists about the wire in the direction shown in diagram 239.

2) An instant later, the polarity of the voltages existing on the wire reverses.

3) When the voltage on the wire reverses, the flux lines of the field also try to reverse their direction.

4) Most of the lines of flux reverse, but some of them remain in the same direction, in which case the following condition exists (diag 240).

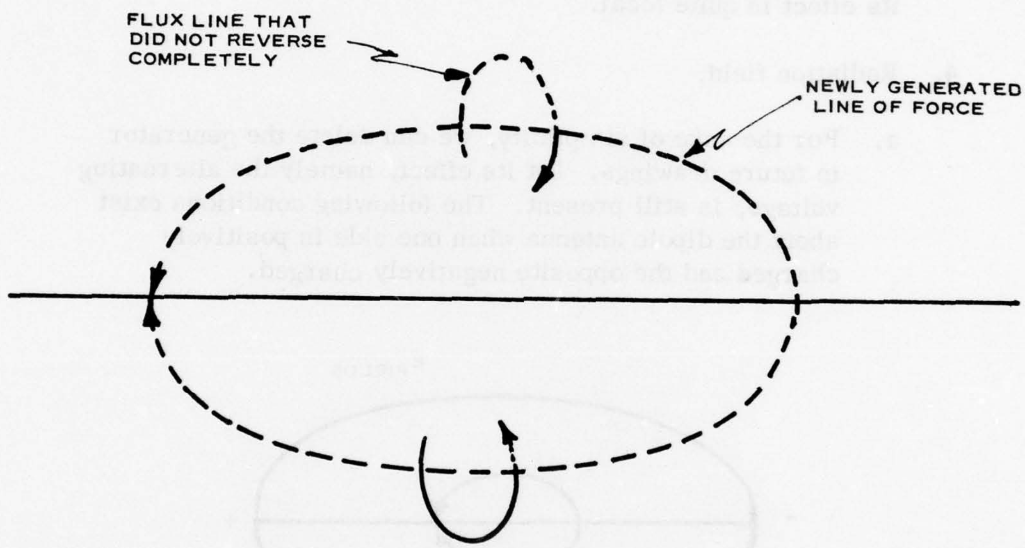


Diagram 240. Reversal of lines of flux.

5) The newly generated force repels the old flux field away from the wire at the speed of light.

6) The preceding discussion dealt only with the field created by the voltage difference at both ends of wire.

7) The current passing through the wire develops an additional field moving away from the wire. The two fields are identical but are displaced in time by 90° or one-quarter cycle.

5. Polarization.

   a. The magnetic and electric fields about a radiating conductor exist, each in a particular plane, as plane waves and are perpendicular to each other. The polarization of an antenna is determined by the direction of the electric plane wave. An antenna erected horizontal to the earth's surface is said to be horizontally polarized; an antenna erected in a vertical position is said to be vertically polarized. The type of polarization to use in a specific antenna application depends upon the type of transmission desired. These factors should be considered before attempting to determine the desired polarization for a specific antenna installation.

6. Antenna fundamentals.

   a. The function of an antenna is to transfer to distant points, in the form of an electromagnetic wave, the radio-frequency energy generated by the transmitter.

      1) The radiated wave in traveling through space is intercepted by the receiving antenna, and a voltage is induced on the antenna.

      2) The magnitude of the voltage induced on the receiving antenna depends primarily upon the intensity of the radiated wave; and the intensity, in turn, depends mainly upon the transmitting-antenna length and height, and the amount of current flowing in it.

      3) The current in the transmitting antenna, at a given frequency and power input, is greatest when the antenna reactance at that particular frequency is approximately zero. The antenna is then said to be resonant at the frequency of the applied wave.

7. Length determination.

   a. Derivation: The shortest length of wire that can be made resonant is that which is just long enough to allow an electric

charge to travel from one end to the other, and back again, during the time of one cycle of the applied radio-frequency wave. Since the charge travels with the velocity of light, or 300,000,000 meters per second, the distance covered in one cycle is equal to the velocity divided by frequency, or

$$\tau = \frac{300,000,000 \text{ meters}}{f}, \qquad \tau = \text{Wavelength.} \qquad (60)$$

f = Frequency in cycles.

$$\tau = \frac{300,000 \text{ meters}}{f}, \text{ or} \qquad \tau = \text{Wavelength.} \qquad (61)$$

f = Frequency in kilocycles.

$$\tau = \frac{300 \text{ meters}}{f}. \qquad \tau = \text{Wavelength.} \qquad (62)$$

f = Frequency in Megacycles.

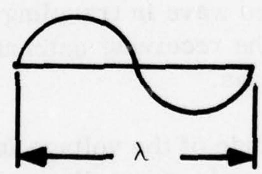


Diagram 241. Wavelength of one cycle.

b. The shortest length of a resonant wire, in wavelength, is equal to one-half of the value found by using the above formula.

Example: The shortest length of wire that is resonant at 150 mc is calculated by equation (62) as follows:

$$\tfrac{1}{2} \text{ wave antenna length} = 0.5 \times \frac{300}{150 \text{ mc}} = 1 \text{ meter.}$$

In other words, a wire one-half wavelength long at 150 mc is 1 meter long. A more practical formula is evolved by considering the velocity of light in feet.

$$\tau = \frac{984 \text{ feet}}{f}. \qquad \tau = \text{Wavelength.} \qquad (63)$$

f = Frequency in megacycles.

Using this formula, the length of wire in the preceding example is calculated by equation (63) as follows:

$$\tfrac{1}{2} \text{ wave antenna length} = \frac{0.5 \times 984}{150 \text{ mc}}.$$

8. Transmission lines.

a. The term "transmission line" is applied to a line employed to conduct or guide electrical energy from one point to another. In the old days, radio engineers had little interest in these lines although power and telephone engineers made wide use of them. The progress of radio, and particularly the utilization of higher frequencies, led to a wider use of transmission lines in radio circuits. The speed at which electromagnetic energy can travel in free space is 186,000 miles per second. This speed is so great that in many applications it can be assumed to be instantaneous. But there are other circuits in which time, even though infinitely short in duration, becomes an all-important factor. The transmission lines used to carry rf power are typical of the circuits in which time cannot be ignored.

b. Types of transmission lines.

1) Perhaps the simplest type of transmission line in use today is the two-wire open line in which two conductors are supported parallel to each other at some fixed distance as shown in diagram 242.

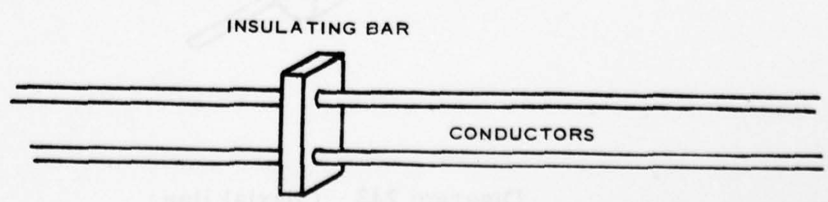


Diagram 242. Open-wire transmission line.

a) The advantages of this type of line are ease and simplicity in construction, low cost, and ability to handle large amounts of power.

1. The two-wire transmission line is most often used by commercial power companies as well as in telephone and telegraph installations.

2. It may also be used in medium- and low-frequency radio installations as a connecting link between the antenna and the receiver or transmitter.

b) Its principle disadvantage is the fact that it has large radiation losses at higher frequencies and is, therefore, practically useless for this work.

2) Another of the more prominent types of transmission lines is the concentric line or, as it is usually called, the coaxial line. As shown in diagram 243, it is constructed by placing a conductor at the center of another hollow conductor or shield. The line may be either rigid or flexible in construction.

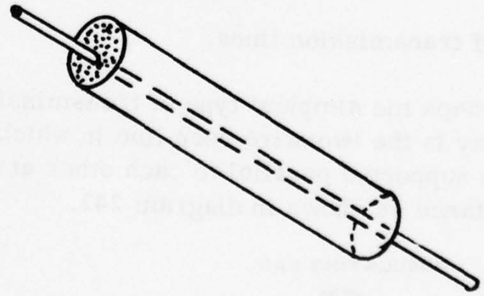


Diagram 243. Coaxial line.

a) The rigid type has air or gas as an insulator except at regular intervals where the center conductor is mechanically supported by insulating material.

b) The flexible type usually has an insulating material, such as polystyrene or teflon, throughout its entire length. The flexible coaxial line is the type most commonly encountered today in radar and high-frequency radio systems since it is easy to handle during installation and requires very little space in comparison to other lines.

c) Generally, the advantages of a coaxial line are its ease of installation and the fact that it has no radiation losses.

d) Disadvantages are the high cost of construction and the fact that insulation losses due to leakage are so large at very high frequencies that its use at these frequencies is prohibitive.

e) A special type of coaxial line having two center conductors is sometimes used. Its losses are much higher than those of a comparable, single-conductor line, and its only advantage is that it is electrically balanced with respect to ground. This is because both center conductors have the same distributed capacity to ground in lieu of the unbalance which is inherent in the construction of the single coaxial line (diag 244).

3) The construction of the twisted-pair line (diag 245) is simple and inexpensive. It is simply two insulated conductors twisted together so that their spacing is held fairly constant.

a) The high losses in this type of line prohibit its use at high frequencies.

b) The twisted-pair line is usually used for telephone leads and in ordinary ac applications.

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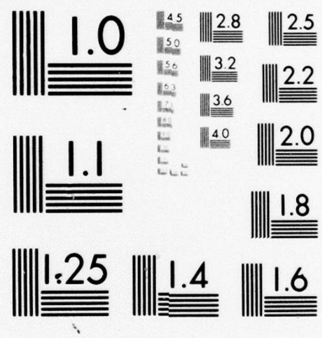

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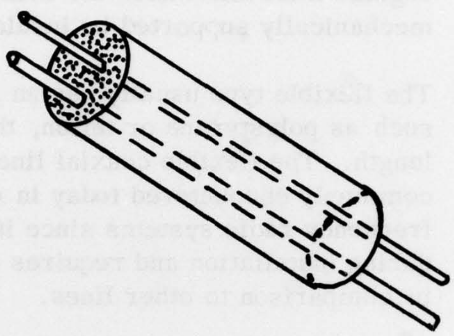

Diagram 244. Two-wire coaxial line.

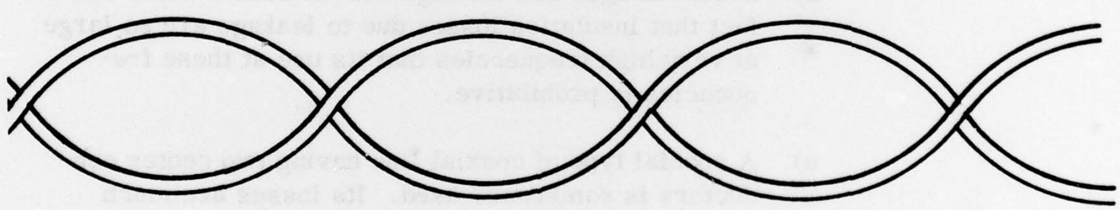

Diagram 245. Twisted-pair line.

9. Waveguides.

a. For transmission lines to transfer power from a source to a load with a minimum of losses, the two conductors should be separated by a space not greater than 1/10th of a wavelength.

1) At the high frequencies and powers used in radar, two conductors held only at 1/10th of a wavelength apart are not sufficiently insulated from each other; and arcing occurs.

2) As a result, waveguides were developed which are simply hollow, metallic tubes that guide rf energy. The dimensions of the waveguide depend upon the frequency of the

rf energy. High-frequency energy travels down the hollow center of the guide to a radiating horn which couples the energy to either a reflecting surface or free space.

> INSTRUCTOR'S NOTE: Exhibit some of the various types of waveguides that are available. Also exhibit coaxial cables if they are available.

SUMMARY:

1. For many reasons, it is desirable to place an antenna or radiating system as high and in the clear as possible. Some form of non-radiating transmission line is utilized to carry energy with as little loss as possible from the transmitter to the antenna proper.
2. The student will find that various types of transmission lines are more efficient than others depending on the frequency of operation and numerous mechanical factors.
3. There is extreme variation in the types and uses of antennas depending on the conditions under which they are to operate.
4. Antennas and transmission lines are an important part of the study of electronics.

LESSON PLAN

SYNCHRO DEMONSTRATION

OBJECTIVE:

1. To understand the purpose and operation of synchros, and

2. To learn how synchros can be used in the transmission of angular-position data.

INTRODUCTION:

The synchro is sometimes called a selsyn (a shortened form of self-synchronous), a synchrotic, or an autosyn. It is a device used for the electrical transmission of angular-position data. Synchros are of two types: synchro transmitter and synchro receiver. The synchro transmitter is sometimes referred to as a synchro motor. All of these terms will appear again when we deal with synchros in the AAFCS M33 radar. The synchro is the main device used for the transmission of angular-position data throughout the AAFCS M33.

PRESENTATION:

1. The basic principle of operation of the synchro is that the voltage induced in a coil by another coil depends on the angular displacement between the two coils (diag 246).

2. A schematic diagram of a synchro is shown in diagram 247.

   a. R4 and R5 in both synchros X and Y are called rotor windings and consist of a coil of wire wound around a solid core. These rotor windings are mounted on an axis through their center which leaves them free to rotate.

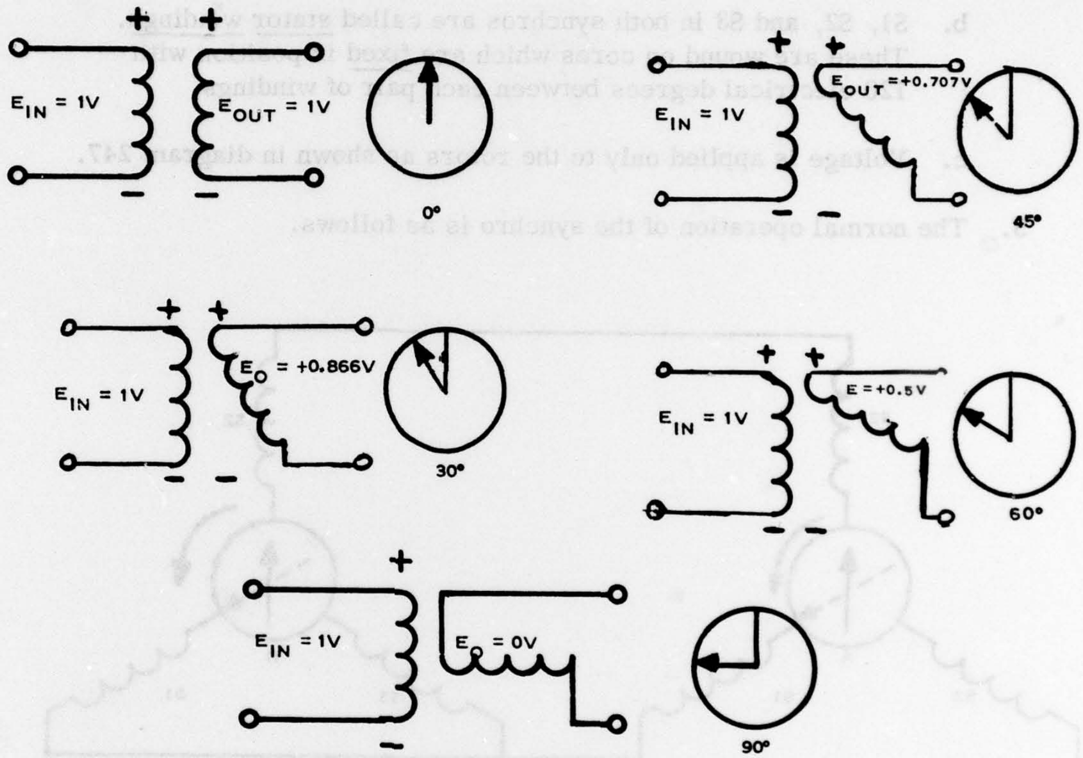

Diagram 246. How angular displacement affects induced voltage.

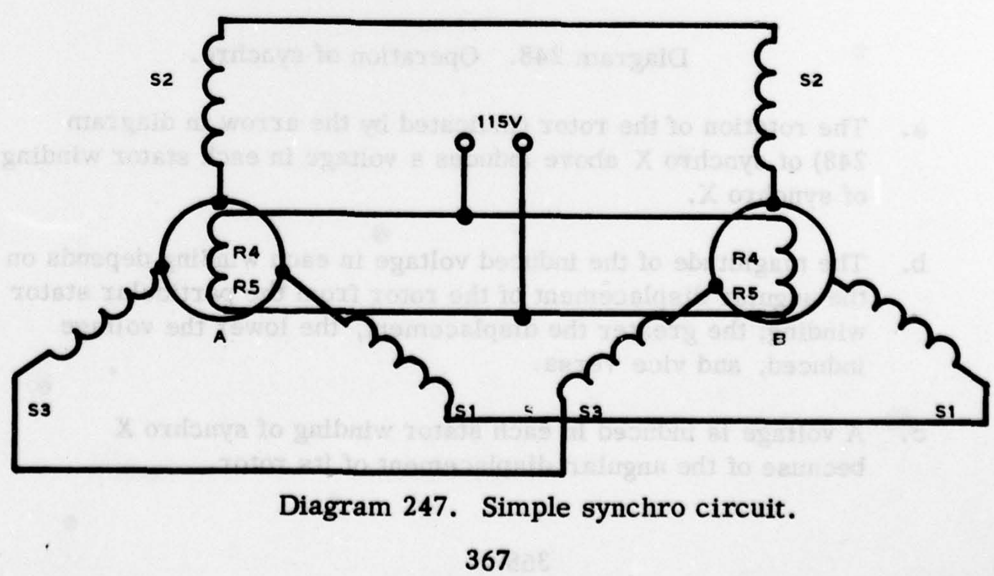

Diagram 247. Simple synchro circuit.

b. S1, S2, and S3 in both synchros are called stator windings. These are wound on cores which are fixed in position with 120 electrical degrees between each pair of windings.

c. Voltage is applied only to the rotors as shown in diagram 247.

3. The normal operation of the synchro is as follows.

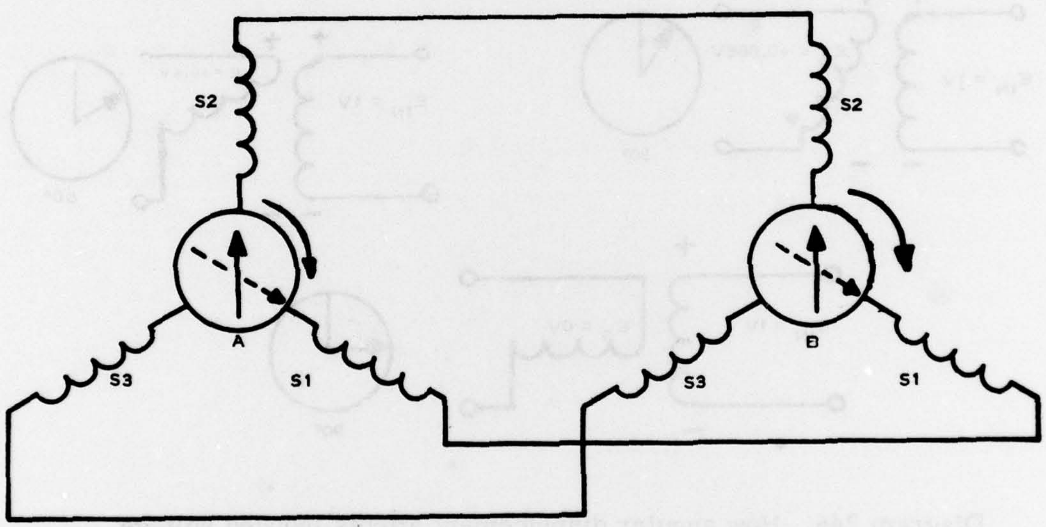

Diagram 248. Operation of synchro.

a. The rotation of the rotor (indicated by the arrow in diagram 248) of synchro X above induces a voltage in each stator winding of synchro X.

b. The magnitude of the induced voltage in each winding depends on the angular displacement of the rotor from the particular stator winding; the greater the displacement, the lower the voltage induced, and vice versa.

c. A voltage is induced in each stator winding of synchro X because of the angular displacement of its rotor.

d. These voltages cause current to flow in the stator windings and cause the rotor of synchro Y to rotate.

e. Rotor Y rotates until it has the same angular position as rotor X, thus inducing the same voltages in the stator windings of synchro Y as were induced in the stator windings of synchro X.

f. No potential difference exists when this condition is achieved; and consequently, no current flows in the stator windings.

4. Troubleshooting.

a. When errors are made in the connections of synchros or when troubles develop in synchros, easily recognizable symptoms appear.

b. Some of the common troubles are listed below.

COMMON TROUBLES:

	Symptoms	Probable causes
1.	In phase, loss of torque. 180° error between rotors and loss of torque.	Open circuit in rotor lead (one).
2.	No movement.	Open circuit in rotor lead (both).
3.	Erratic operation.	Open stator leads.
4.	Error of 180° between rotors.	Rotor leads reversed.
5.	Synchros turn in opposite directions.	Stator leads reversed (any two).
6.	Indication of 120-degree error displacement between rotors.	Cycle rotation of stator leads (stator leads rotated in order S1 to S2, S2 to S3.)

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SUMMARY:

1. The synchro is a device for the electrical transmission of angular position data.
2. The two types of synchros are transmitters or motors and receivers.

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